## Remarks

The Examiner's Office Action mailed September 9, 2003 and the references cited therein have been reviewed. In this response, Applicant's claims 1-28 have been canceled and new claims 29-61 have been added. Applicant requests that the application be reexamined and reconsidered in view of these amendments and further in view of the following remarks.

In the Office action mailed September 9, 2003, the Examiner rejected Applicant's claims as follows: (a) Claims 1, 3-5 and 10-13 were rejected under 35 U.S.C. § 103(a) as being unpatentable over *The Journal of Food Science* article entitled "Steam Surface Pasteurization of Beef Frankfurters," 1994, 59(1) 1-5; (b) claims 6-8, 14-16, and 23 -25 were rejected under 35 U.S.C. § 103(a) as being unpatentable over the *Journal* article in view of U.S. Patent No. 5,952,027, issued to Singh; (c) claims 9 and 17 were rejected under 35 U.S.C. § 103(a) as being unpatentable over the *Journal* article in view of U.S. Patent No. 5, 707,672, issued to Taguchi, et al.; (d) claims 18-21 were rejected under 35 U.S.C. § 103(a) as being unpatentable over Singh; (e) claim 22 was rejected under 35 U.S.C. § 103(a) as being unpatentable over Singh in view of Taguchi, et al.; (f) claim 26 was rejected under 35 U.S.C. § 103(a) as being unpatentable over the *Journal* article; (g) claim 27 was rejected under 35 U.S.C. § 103(a) as being unpatentable over the *Journal* article; and (h) claim 28 was rejected under 35 U.S.C. § 103(a) as being unpatentable over the *Journal* article in view of Taguchi, et al.

Applicant's claims 1-28 have been canceled and replaced with new claims 29-61.

Applicant's New Claims 29-61

Applicant's claims 29-39 call for a surface pasteurization process for precooked food

products wherein (a) the outer surface of the food product is exposed to infrared energy by

continuously conveying the product through an infrared oven and then (b) the product is packaged.

The infrared pasteurization step is conducted such that there is no substantial change in the color of

the product. Claim 29 also requires that substantially no additional heating of the food product occur

between the infrared treatment step and the packaging step. Claim 30 requires that no intervening

cooling step be performed and claim 31 states that there is substantially no increase in core

temperature. Claims 32 and 33 require at least a 3 log reduction in surface bacteria and claims 34

and 35 call for infrared oven temperatures of at least 700 or 750°F.

Applicant's new claims 40-49 call for a surface pasteurization process wherein a precooked

food product is exposed to infrared energy by continuously conveying the food product through an

infrared oven. The infrared oven comprises infrared elements positioned in a manner effective for

substantially surrounding and directly irradiating all of the food product laterally as the food product

is conveyed through the oven. Claim 43 requires that the oven include infrared elements positioned

adjacent the sides of the product. Claim 44 provides that there be substantially no change in product

surface color. Claim 49 provides that there is substantially no increase in core temperature. Claims

45 and 48 require, respectively, that no intervening heating step or cooling step be performed prior

to packaging. Claim 46 calls for at least a 3 log reduction in surface bacteria and claim 47 calls for

an infrared oven temperature of at least 700°F.

Applicant's new claims 50-61 also call for a surface pasteurization process wherein a

precooked food product is exposed to infrared energy by continuously conveying the food product

through an infrared oven. Claim 50 requires that the infrared oven include: a conveyor which

continuously conveys the product through the infrared oven; a plurality of arched lateral upper

infrared elements extending over the conveyor belt; and a plurality of lower infrared elements

positioned beneath the belt. Claim 51 states that the lateral upper infrared elements have an inverted

U-shape. The requirements of claims 52, 53, and 55-61 are similar to those of claims 41, 42, and

44-49. Claim 54 requires that the upper and lower infrared elements substantially surround the food

product laterally.

The References Cited in the Office Action Mailed September 9, 2003

The Journal article cited in the Examiner's Office action mailed September 9, 2003 discloses

a process for reducing surface bacterial contamination on beef frankfurters wherein the frankfurters

are subjected to a flash steam heating procedure in a noncontinuous pressurized chamber followed

immediately by an evaporative cooling step. In addition, the article indicates that the color of the

frankfurters was noticeably changed. The resulting color difference is said to have later diminished

in some way over an extended storage period.

Taguchi, et al. disclose a "method for sterilizing and packaging solid foods" wherein the solid food product (e.g., cooked rice, noodles, pasta, or vegetable and meat mixtures") are placed in a perforated retainer and are then heated throughout (see e.g., col. 3:10-15), i.e., from surface to core, with steam in a noncontinuous pressurized heating chamber. The product must then be cooled in

the retainer prior to being transferred to a sterile package.

The Singh patent discloses a method for browning and crisping precooked whole muscle meat products which significantly changes the color and other surface characteristics of the product. The precooked product is dipped or drenched in liquid smoke or other browning agent and is then subjected to an energy source of a type and in a manner effective for causing the Maillard browning reaction to occur in the product surface. The patent teaches that the energy source will preferably be either a circulating air or impinging air oven and the browning time will preferably be such that increases in the internal temperature of the product are minimized. The patent also suggests that laser light, microwave energy, or infrared radiation could be used for browning the product and includes an example (Example 5) wherein a turkey breast was browned by exposure to what appears to have been a noncontinuous, medium range infrared radiation source. The highest browning temperature disclosed is 570°F (see Example 1) and the patent teaches that the preferred maximum temperature is 554°F (290°C). The browning process also preferably includes the step of removing purge material from and drying the product surface prior to application of the browning agent. The patent states at Col. 4, 12-14 that circulating hot air or infrared radiation could be used in the drying step.

The Singh patent does not discuss or suggest any packaging, cooling, or other steps following

the browning procedure. Nor does Singh suggest any adaption or modification of the browning

process whereby the browning process could be effectively used to produce browned packaged

products which are adequately surface-pasteurized for sale. Nor does Singh disclose or suggest (a)

a continuous infrared oven which is either constructed or operated in the manner called for in

Applicant's claims or (b) any other type of continuous infrared oven.

Supplemental Information Disclosure Statement

In conjunction with this Amendment and Response, Applicant has submitted a Supplemental

Information Disclosure Statement describing the "Unitherm browning process." The Unitherm

browning process is the process described and claimed in the Singh patent. The Unitherm browning

process was developed by Applicant and has been on-sale in the U.S. since 1993. The Supplemental

Information Disclosure Statement also includes a copy of a summary judgment Order entered by

Chief Judge Robin J. Cauthron of the U.S. District Court for the Western District of Oklahoma

finding all of the claims of the Singh '027 patent invalid in view of the Unitherm browning process.

In the Unitherm browning process, precooked whole muscle turkey breasts and other

products are removed from their cooking bags and are preferably then first conducted through a

continuous infrared oven, solely for the purpose of melting purge material from and drying (i.e.,

removing free moisture from) the product surface. After purge removal, the product is dipped in or

deluged with liquid smoke of other browning liquid and conveyed through a browning oven. The

product is then subjected to an intervening chilling step prior to packaging.

The infrared purge removal and drying step of this browning process has been used solely

for melting purge and removing free moisture from the product surface, not for surface

pasteurization. Moreover, the infrared oven uses only upper infrared elements and does not have any

elements under the belt for irradiating the bottom of the product. The positioning of elements

beneath the belt has not been necessary for purge removal and drying. Moreover, the positioning of

elements beneath the belt would pose a serious safety hazard because the lower elements would

ignite the purge material as it drips from the product.

Also submitted with Applicant's accompanying Supplemental Information Disclosure

statement are copies of: (a) Ginzburg, "Application of Infra-red Radiation in Food Processing"

disclosing an infra-red meat curing process which significantly heats the interior of the product, dries

the product out, and darkens the product considerably; (b) Dagerskog, "Infra-Red Radiation for Food

Processing II, Calculation of Heat Penetration During Infra-Red Frying of Meat Products" wherein

infra-red radiation is used for frying meat; and (c) Hallstrom, et al., "Heat Transfer and Food

Products" involving radiant cooking procedures resulting in significant heat import and product color

change. The Hallstrom et al. article includes a diagram (Fig. 5.39) of a continuous infrared oven

with elements above and below the conveyor; however, the elements do not surround the product,

none of the elements are arched, and the bottom of the product is shielded by a pan in which the

product is carried during the cooking operation.

The Cited References Neither Disclose Nor Suggest Numerous
Key Features Called For In The Pending Claims

In view of the above, Applicant respectfully submits that the references cited in the Office action mailed September 9, 2003 and the additional references discussed herein neither disclose nor suggest several key features called for in claims 29-61. Examples of such features include, but are

not limited to:

- 1. Surface pasteurizing a precooked food product as called for in claims 29-39 by exposing the outer surface of the food product to infrared energy in a manner such that substantially no change in color is produced and then packaging the product with no intervening heating step.
- 2. Surface pasteurizing a precooked food product as called for in claims 40-49 and 54 by continuously conducting the product through an infrared oven having elements which substantially surround and directly irradiate the product laterally.
- 3. Surface pasteurizing a precooked product by conveying the product through an infrared oven of this type having infrared elements which are positioned adjacent to and which directly irradiate the sides of the product. (Claim 43)
- 4. Surface pasteurizing a precooked product as called for in claims 50-61 by continuously conveying the product through an infrared oven have a plurality of

arched lateral upper infrared elements positioned over the conveyor and a plurality of lower infrared elements positioned below.

- 5. The use of a continuous infrared oven of this type wherein the arched lateral upper infrared elements have an inverted U-shape.
- 6. Continuous infrared surface pasteurization processes, for precooked products, of the types called for in claims 30, 48, and 59 wherein no intervening cooling step is performed prior to packaging.
- 7. A continuous infrared surface pasteurization process of this type wherein substantially no core temperature increase occurs. (Claims 31, 49, and 60)
- 8. Continuous infrared surface pasteurization processes, for precooked products, of the types called for in claims 32, 33, 46, and 55 wherein at least a 3 log reduction in live bacteria on the surface is achieved.
- 9. Continuous infrared surface pasteurization processes, for precooked products, of the types called for in claims 29, 45, and 55 wherein substantially no additional heating of the food product occurs prior to packaging.
- 10. A continuous infrared surface pasteurization process for precooked products wherein the infrared oven is operated at a temperature of at least 700°F or at least 750°F (Claims 34, 35, 47, 56, and 58) and/or a residence time of not more than two minutes (Claim 58).

11. A continuous infrared surface pasteurization process for precooked products wherein

the bottom of the food product is directly irradiated through the oven belt. (Claims

41, 42, 52, and 53)

12. Continuous infrared surface pasteurization processes of the type called for in claims

44 and 61 for precooked products wherein substantially no change in surface color

occurs.

The Inventive Process Also Satisfies A Recognized And Persistent Need In The Industry, Provides Unexpected And Surprising Results, And Has Already Shown

Impressive Commercial Success

In addition to the above, Applicant's inventive surface pasteurization process satisfies a

recognized, persistent need in the industry and provides unexpected and surprising results. The

inventive continuous infrared process for precooked food products has also shown impressive

commercial success and has proven to be so surprisingly effective that it is now recognized and

recommended by the USDA Food Safety Inspection Service.

Included with this response are: (a) an affidavit of the inventor David Howard; (b) a

published study of the inventive infrared surface pasteurization process by N. Gande and P. Muriana

entitled "Prepackage Surface Pasteurization of Ready-to-Eat Meats with a Radiant Heat Oven for

Reduction of Listeria monocytogenes," Journal of Food Protection, Vol. 66, No. 9, 2003, Pages

1623-30. (Howard Affidavit Exhibit 1); and (c) a copy of the recent USDA Food Safety Inspection

Service (FSIS) compliance guidelines to control Listeria monocytogenes in post-lethality exposed

ready-to-eat meat and poultry products. (Howard Affidavit Exhibit 2)

As seen in these items and as more fully explained in the Howard Affidavit, a long-felt need

has been recognized in the industry for an effective surface pasteurization process for precooked

ready-to-eat foods which does not substantially affect the color or other characteristics of the

product. As early as 1996, the USDA-FSIS and the Food and Drug Administration (FDA) issued

zero tolerance requirements for Listeria monocytogenes in ready-to-eat foods. However, the

approaches used heretofore have clearly not been adequate. Illnesses, deaths, and large recalls of

ready-to-eat foods have continued to occur due to ongoing contamination problems. Moreover, from

1998 to 2001, the FSIS sampling program for ready-to-eat foods showed continuing Listeria

monocytogenes incidents rates of 5.7% for sliced luncheon meats, 4.4% for small diameter sausages

and hot dogs, and 3.1% for roast beef. (See Howard Affidavit Exhibit 1, page. 1623.)

As to why the procedures developed and used heretofore in the industry have proven

inadequate, it is important to note that the tests performed by Gande and Muriana showed that kill

rates for surface bacteria could not be accurately predicted based solely upon single point or even

multi-point surface temperature readings.

It is clear from various high surface temperature measurements we obtained that the accompanying microbial reduction was not in line with what would be expected on the basis of extrapolation from D-values (decimal reduction times) for the inoculated pathogens. Unlike the heating of fully cooked products to a specific internal temperature so that the entire product from the center outward has reached at least

the target temperature, brief surface heating may not necessarily penetrate all of the cuts, folds, and crevices that can be accessed by bacteria, and therefore single-point, or even multi-point, temperature readings for the outermost surface may be of limited practical application. (*Id.* at 1627)

The unexpected success of the inventive infrared surface pasteurization process for achieving necessary kill rates and satisfying other product characteristic objectives for treatment of precooked ready-to-eat products are confirmed in the Gande and Muriana study and are discussed in the Howard Declaration in detail. These results are also confirmed and corroborated by the adoption of the inventive prepackage surface pasteurization process in the FSIS guidelines for control of *Listeria monocytogenes* in post-lethality exposed ready-to-eat meat and poultry products. (Howard Declaration Exhibit 2, see pgs. 1-4 and 10-11)

In addition to adopting the inventive process, the guidelines expressly provide that food processors can use the published Gande and Muriana research study of the inventive process as validation provided that the equipment and conditions used correspond to the Unitherm equipment and conditions which were used in the study and are called for in Applicant's claims. (*Id.* at pages 4, 10, and 11) Moreover, the inventive process is the only prepackage surface pasteurization process adopted in the guidelines and processors choosing to use other prepackage surface pasteurization processes must perform their own scientific validation studies showing acceptable reduction of *Listeria monocytogenes*. (*Id.* at pg. 4)

The non-obviousness of the inventive infrared surface pasteurization process is also confirmed by the impressive commercial success achieved thus far. As set forth in the Howard

Attorney Docket No.: Unitherm-2 (00-627)

Amendment and Response to Office Action

Page 24

Declaration, the inventive process and the specific continuous infrared oven therefor manufactured

by Applicant's company, Unitherm Food Systems, Inc., were first offered to the industry for sale and

use in 2002. Unitherm's promotional activities related thereto have also been minimal, consisting

only of displays at two trade shows and a single trade journal advertisement costing about \$15,000.

Despite this meager promotional effort, Unitherm's sales of single lane and double lane oven

systems from 2002 to the present date have amounted to total sales of 44 processing lanes. At the

most recent of the two above-mentioned trade shows held October 29-31, 2003, inquiries for the

potential sale of a total of 60 additional processing lanes were received.

\* \* \* \* \*

In view of the above, Applicant respectfully submits that all of Applicant's claims 29-61 are

in condition for allowance. Applicant therefore requests that any and all of the Examiner's rejections

and objections be withdrawn and the Examiner allow claims 29-61.

**PATENT** 

Attorney Docket No.: Unitherm-2 (00-627)
Amendment and Response to Office Action

Page 25

This paper is intended to constitute a complete response to the Office action mailed September 9, 2003.

Respectfully submitted,

Dennis D. Brown

Registration No. 33,559

FELLERS, SNIDER, BLANKENSHIP,

**BAILEY & TIPPENS** 

The Kennedy Building

321 South Boston, Suite 800

Tulsa, OK 74103-3318

918/599-0621 (phone)

918/583-9659 (fax)

234100.1



APPLICANT:

David Howard

**SERIAL NO.:** 

09/777,472

FILED:

02/06/2001

FOR:

Pasteurization of Food Products

**ART UNIT:** 

1761

**EXAMINER:** 

George Chan Pui Yeung

CONFIRM. NO.:

4276

## **DECLARATION OF DAVID HOWARD**

PECEIVED TC 1700

I, David Howard, declare that the following statements are based on my personal knowledge and that they are true to the best of my knowledge and belief.

- 1. I am the President and custodian of records of Unitherm Food Systems, Inc. ("Unitherm") and am the inventor in the above-referenced patent application.
- 2. Attached hereto as Exhibit 1 is a study by Gande and Muriana entitled "Prepackaged Surface Pasteurization of Ready-to-Eat Meats With a Radiant Heat Oven for Reduction of Listeria Monocytogenes," published in 2003 in *The Journal of Food Protection*, Vol. 66, No. 9, pgs. 16, 23-30. This study embodied and confirmed the effectiveness of the infrared surface pasteurization process now called for in the claims of the above-referenced application and now also being sold by Unitherm.

- 3. As with the infrared process claimed in this patent application, the process tested and procedures used in the Gande and Muriana study involved the following:
  - a. The surface pasteurization of various types of precooked, ready-to-eat food products inoculated with *Listeria monocytogenes*, including, for example, precooked, ready-to-eat products such as whole and split rounds of roast beef, whole corned beef logs, formed deli ham, whole muscle deli ham, and turkey bologna. Each of the roast beef, corned beef, and ham product items weighed in the range of from 4 to about 13 pounds and the turkey bologna was processed in 2-pound sections.
  - b. Conveying the inoculated food items through a Unitherm electric infrared oven which was operated at an 80% setting (475°F) for the turkey bologna product and was operated at full power (750°F) for all of the other products tested. As confirmed by the photographs provided in Figs. 1A, B, and D and Figs. 2C and D, the Unitherm electric infrared oven used in the study corresponded in all relevant respects to the infrared oven described in the specification and shown in the drawings of the application and as called for in the claims. The infrared oven was a continuous oven comprising: an elongate housing having inverted U-shaped inlet and outlet openings; a stainless steel wire conveyor belt; a series of lateral inverted U-shaped infrared elements extending over the carrying run of the conveyor; and a series of lateral lower infrared elements positioned beneath the carrying run. The upper and lower infrared elements substantially surround the food products laterally as they are conveyed through the oven and are effective for

directly irradiating the entire outer surface of each food product with infrared energy as the food product travels through the oven.

- 4. The tests performed by Gande and Muriana on contact-inoculated hams involved oven processing times of only 45-75 seconds and yielded 2.7 to 3.9 log reductions in live bacteria on the product surfaces. Processing times of from only 60-90 seconds for contact-inoculated roast beef yielded 2.5 to 3.8 log reductions in surface bacteria.
- 5. The tests by Gande and Muriana described in the study produced no discernable changes in product color.
- 6. Gande and Muriana concluded and confirmed that this surface pasteurizing process is effective for reducing incidental contamination that may be acquired during post-processing handling and is particularly effective for use just prior to packaging. The product will most preferably be packaged while still hot immediately following the inventive surface pasteurization procedure.
- 7. The published study of Gande and Muriana also documents and confirms both (a) the recognized and persistent long felt need for a truly effective prepackage surface pasteurization process for ready-to-eat foods and (b) the unexpected and surprising success of the process claimed in this patent application for achieving the needed results.

- As additional evidence showing the scientific and commercial success of the inventive 8. process as well as the successfulness of the inventive process in addressing the long-felt need for an effective prepackaged surface pasteurization procedure for ready-to-eat meats, attached hereto as Exhibit 2 is a copy of recent compliance guidelines issued by the USDA-Food Safety Inspection Service (FSIS) to control Listeria monocytogenes in post-lethality exposed ready-toeat meat and poultry products. The requirements of the final rule provide three alternative lethality treatments which ready-to-eat meat and poultry processing plants can use in their mandatory control programs for Listeria monocytogenes. The guidelines cite the claimed prepackage infrared surface pasteurization process, now sold by Unitherm, as a preferred procedure coupled with a post-packaging water bath and cite the Gande and Muriana study as an acceptable reference which processors can use for validation of their use of the process. (See pages 1-4, 10, and 11.) The inventive infrared procedure is the only prepackage process recommended in the guidelines. Processors electing to use other procedures must first confirm through appropriate validation studies that such other procedures are also effective for achieving the required reduction of Listeria monocytogenes. (Page 4.)
- 9. Additional tests and demonstrations performed by Unitherm as well as the successful operation of the inventive process by Unitherm's customers also confirm the effectiveness of the inventive process for achieving the desired results without substantially changing the color or other surface characteristics of the products and without increasing the product core temperature.

- 10. The continuous infrared ovens manufactured by Unitherm for use in the inventive process are of two basic types. The first is a single processing lane oven of the type depicted in the application drawings having only a single processing tunnel and conveyor. The other is a double processing lane oven which is essentially the same as the single lane oven except that it includes two parallel processing tunnels and conveyors.
- 11. Unitherm began offering the inventive surface pasteurization process and its infrared ovens therefore to the market beginning in 2002. Since beginning sales in 2002, the number of ovens sold by Unitherm for commercial use in the inventive infrared surface pasteurization process total 44 processing lanes.
- 12. As further evidence of the recognized long-felt need for the inventive process and its high level of commercial success, Unitherm's promotional expenditures pertaining to the inventive process and its infrared oven systems for use in the process have been minimal. Since beginning sales of the pasteurizing process and oven in 2002, Unitherm has promoted the process and oven at only two trade shows. As for advertising, Unitherm's only expenditure has been \$15,000 for a one-half page advertisement in a trade magazine. The most recent of the two trade shows where the pasteurizing process and infrared oven were presented was held October 29-31, 2003. Unitherm is currently processing inquiries received at the October 29-31, 2003 trade show amount to the potential sale of a total of 60 additional processing lanes.

I declare that all statements made herein of my own knowledge are true, all statements made herein on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and may jeopardize the validity of the application or any patent issuing thereon.

DAVID HOWARD

Date: 16 December 2003

(Signature)

225950.1

## Prepackage Surface Pasteurization of Ready-to-Eat Meats with a Radiant Heat Oven for Reduction of *Listeria monocytogenes*

NANDITHA GANDE1 AND PETER MURIANA1.2\*

<sup>1</sup>Department of Animal Science and <sup>2</sup>Oklahoma Food and Agricultural Products Research and Technology Center, Oklahoma State University, Stillwater, Oklahoma 74078-6055, USA

MS 02-427: Received 26 November 2002/Accepted 26 March 2003

### **ABSTRACT**

In this paper, a thermal process for the surface pasteurization of ready-to-eat (RTE) meat products for the reduction of Listeria monocytogenes on such products (turkey bologna, roast beef, corned beef, and ham) is described. The process involves the passage of products through a "tunnel" of heated coils on a stainless steel conveyor belt at various treatment times relevant to the manufacture of processed meat for the surface pasteurization of RTE meat products. Two inoculation procedures, dip and contact inoculation, were examined with the use of a four-strain cocktail of L. monocytogenes prior to heat processing. With the use of radiant heat prepackage surface pasteurization, 1.25 to 3.5-log reductions of L. monocytogenes were achieved with treatment times of 60 to 120 s and air temperatures of 475 to 750°F (246 to 399°C) for these various RTE meats. Reduction levels differed depending on the type of inoculation method used, the type of product used, the treatment temperature, and the treatment time. Prepackage pasteurization (60 s) was also combined with postpackage submerged water pasteurization for formed ham (60 or 90 s), turkey bologna (45 or 60 s), and roast beef (60 or 90 s), resulting in reductions of 3.2 to 3.9, 2.7 to 4.3, and 2.0 to 3.75 log cycles, respectively. These findings demonstrate that prepackage pasteurization, either alone or in combination with postpackage pasteurization, is an effective tool for controlling L. monocytogenes surface contamination that may result from in-house handling.

Listeria monocytogenes is a significant foodborne pathogen that is capable of causing foodborne illnesses that may simulate flulike conditions (i.e., listeriosis). Serious infections can further lead to abortions in pregnant women and meningitis. Mortality rates can reach 25 to 30% overall in large outbreaks and may even be as high as 50% (septicemia) to 70% (meningitis) for primary infected individuals or >80% for perinatal-neonatal infections. Consequently, both the U.S. Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS) and the U.S. Food and Drug Administration (FDA) have issued a zero tolerance for this pathogen in ready-to-eat (RTE) foods, declaring it an "adulterant" and "added agent" harmful or injurious to consumers (15).

L. monocytogenes is widespread in the environment and has been found in plants, soil, animals, water, silage, and other processing environment sources. The organism is heat and salt tolerant, can form biofilms on food processing equipment (10), and has the ability to grow at refrigeration temperatures. Like many animal-associated pathogens, L. monocytogenes can gain entry into meat processing facilities through contaminated carcasses and/or boxed beef, poultry, or other meats (14). Epidemiological studies indicate that L. monocytogenes is often transferred through cross-contamination from employees, drains, standing water, residues, floors, and food contact surfaces, suggesting that a finished RTE product can readily acquire L. mono-

cytogenes contamination prior to final packaging while the product is exposed to environmental contamination (9, 12). Thus, sanitation programs are critical in controlling the pathogen in processing environments.

Foods typically associated with listeriosis are foods that are highly processed and have an extended shelf life, foods such as RTE processed meats (6). L. monocytogenes can be found in the environments of food processing facilities, and therefore its elimination from these types of facilities is of particular concern to manufacturers of RTE meats. Alarmingly, the results of USDA-FSIS RTE meat sampling program from 1998 to 2001 showed L. monocytogenes incidence rates of 5.7% for sliced luncheon meats, 4.4% for small-diameter sausages (hot dogs), and 3.1% for cooked roast beef. Since being labeled as an adulterant of RTE foods, L. monocytogenes has been involved in numerous product recalls, foodborne illnesses, and even deaths due to the consumption of contaminated RTE meat products (1-3). One of the largest outbreaks arising from postprocessing contamination of RTE meats, occurring in 1998, involved a large manufacturer of hot dogs and luncheon meats and resulted in 21 deaths and >100 illnesses in 14 states, leading to the recall of 35,000,000 lb of hot dogs and deli meats (1, 2).

Postprocessing contamination of RTE meats with L. monocytogenes has become a major concern to the value-added processed-meat industry, and surface pasteurization is becoming an effective means for reducing the risk posed by such products. Much of the research on meat surface pasteurization has been related to steam pasteurization (i.e.,

<sup>\*</sup> Author for correspondence. Tel: 405-744-5563; Fax: 405-744-6313; E-mail: muriana@okstate.edu.

Frigoscandia, Inc., a manufacturer of equipment for surface pasteurization using steam) of exposed raw beef carcass surfaces to reduce the incidence of Escherichia coli O157: H7 that might end up in trimmings and ground beef (4). The Listeria problems currently encountered in the RTE processed meat industry are the result of a combination of (i) Listeria contamination from the processing environment and from workers and (ii) a high degree of postprocessing product exposure to potential contamination sources and handling practices that could allow incidental surface contamination (worker handling, removal of deli products from cook-in bags, exposed product on trays or carts wheeled into smokehouses, etc.). Various technologies and approaches to help reduce the risk of postprocessing contamination have emerged, including chemical-antimicrobial treatments (5, 11, 13), irradiation (not yet approved for RTE meats) (16), and thermal processes such as postpackage submerged water pasteurization (7, 8). These techniques can be used either individually or in combination to produce a "hurdle" effect on pathogen contaminants. To provide a solution to this problem, we have been studying surface pasteurization as a convenient and effective means of reducing incidental contamination on product surfaces immediately before (prepackage) or after (postpackage) final packaging. Postpackage pasteurization (7) has already been implemented by several large meat processors. The objective of this work was to investigate the effectiveness of a radiant heat oven for the prepackage surface pasteurization of RTE deli meats as a means of controlling L. monocytogenes on fully cooked meat products (turkey bologna, deli ham, corned beef, and roast beef).

## MATERIALS AND METHODS

Bacterial strains. A mixture of four strains of L. monocytogenes (Scott A-2, serotype 4b; V7-2, serotype 1/2a; 39-2, retail hotdog isolate; 383-2, ground beef isolate) was used for the inoculation trials. These strains were made resistant to streptomycin (100 µg/ml; Sigma Chemical Co., St. Louis, Mo.) and rifamycin S/V (10 µg/ml; Sigma) and were plated on general-purpose agar (tryptic soy agar [TSA]; Difco, Becton-Dickinson, Franklin Lakes, N.J.) containing these antibiotics when they were selectively plated for the inoculum cultures. This approach allows the recovery of viable and heat-injured cells without the need for harsh selective media that may prevent the growth of heat-injured cells (e.g., modified Oxford agar) or in lieu of indigenous contaminating bacteria. For the culturing of the bacterial strains, 100  $\mu$ l of thawed frozen culture was transferred to 10 ml of brain heart infusion (BHI) broth and incubated overnight at 30°C; each of the four cultures was then transferred individually to 40 ml of BHI culture and later combined (for a total volume of 160 ml) prior to their use in the dip inoculation treatment. For surface contact inoculation, overnight cultures were mixed in equal proportions, and the mixture (100 µl) was surface plated onto tryptic soy agar (TSA) that was held overnight at 30°C.

Product inoculation. Samples of roast beef (whole and split rounds), corned beef (whole logs), and ham (formed and whole muscle) generally weighed 4 to 13 lb (1.8 to 5.9 kg), and turkey bologna samples were composed of ~2-lb sections. Except for two lots of roast beef (received frozen and allowed to thaw), all products were received fresh and refrigerated from commercial

processors as they would normally be shipped for sale to retailers without the additional thermal processing. The products were stored at 3°C (37.4°F) upon receipt and were removed from refrigerated storage just prior to inoculation, so the internal temperature was the same. Immediately before they were used, products were taken from refrigerated storage, removed from their packaging wrap, and inoculated with *L. monocytogenes* by the dip inoculation method or by a contact inoculation method. Control samples were also inoculated for each replication trial but were not heated; these samples were used to determine the basal recovery level for the inoculated microorganisms.

For the dip inoculation method, ca. 160 ml of a four-strain mixture (i.e.,  $4 \times 40$  ml) of *L. monocytogenes* was placed in a stainless steel bowl into which individual product pieces were dipped and rotated until all exposed surfaces had been wetted with the mixed culture. Product pieces were then placed on a sterile tray for 5 min to allow excess culture to drain off and were then placed on a conveyor belt leading into the radiant heat oven. With the use of the dip inoculation method, inoculation levels of ca. 1  $\times$  109 to 3  $\times$  109 CFU per product were typically achieved, as determined by recovery from inoculated but unheated control samples.

For the contact inoculation method, sponge-foam padding material (ca. 5 to 6 cm thick) was cut to the shape of a petri plate, autoclaved in foil-covered beakers, and used to pick up the mixed-strain inoculum lawn from inoculated petri plates after overnight incubation on agar plates with the use of a contact and twist motion. The inoculum was then contact inoculated onto the surface of the product with the same twist motion. The inoculated product was then placed on the conveyor leading into the radiant heat oven. As determined from nonheated control samples, the contact inoculation method also provided initial L. monocytogenes levels of  $1 \times 10^9$  to  $3 \times 10^9$  CFU per product sample.

Prepackage pasteurization with a radiant heat oven. A radiant heat oven (480 V, 30 A; Infrared Grill) was obtained from Unitherm Foodsystems (Bristow, Okla.) and installed in our pathogen processing pilot plant (Fig. 1A and 1B). The oven consisted of a stainless steel conveyor belt with heating elements positioned above and below it (Fig. 1). Heating coils had 12 in. (30.5 cm) of lateral clearance at the level of the conveyor belt and 8 in. (20.3 cm) of vertical clearance above the belt; separate bottom coils were positioned 5 in. (12.7 cm) below the belt. The coils themselves were spaced 2.5 to 3 in. (6.3 to 7.6 cm) apart. Inoculated product pieces were passed through the radiant heat oven (Fig. 1) for various treatment times at full power (no. 5 dial setting for ham and roast beef) or 80% power (no. 4 dial setting for turkey bologna). Products were processed for treatment times of 45 to 120 s depending on the resilience of the product and the throughput requirements of the product's processors; treatment times were adjusted by altering the speed of the belt. Product logs were placed lengthwise on the belt. Half rounds of roast beef were pasteurized both with the cut face facing the end of the oven and with the cut face facing to one side. After passage through the oven, product samples were placed into a sterile bag, chilled in an ice-water slurry, and rinsed with a chilled sterile diluent (50 ml of 0.1% buffered peptone water) to recover cells for microbial analysis (usually within 15 to 20 min); inoculated but unheated control samples were treated similarly. The same procedure was used for all meat samples.

Postpackage surface pasteurization. Postpackage surface pasteurization of fully cooked deli ham, roast beef, and turkey bologna was carried out as described previously with a 50-gal (189-liter) steam-injected temperature-controlled water bath (7).

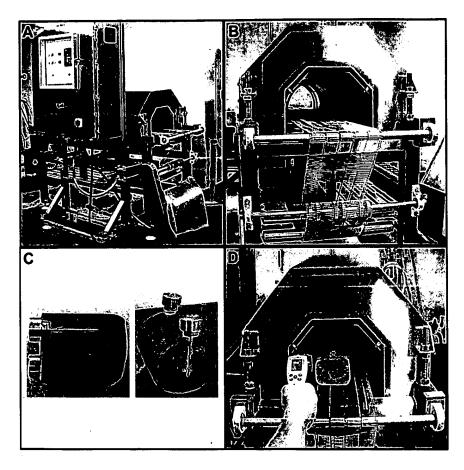


FIGURE 1. The radiant heat oven used in this study. (A) Control box, conveyor belt, and radiant oven. (B) Internal view of heating coils. (C) Attachment of temperature-hardened DataTrace probes to turkey bologna product. (D) Raytek ST80 handheld infrared temperature monitor.

For samples processed by postpackage pasteurization alone (roast beef), we used a 25-ml inoculum. Additional resuspension diluent was used after pasteurization to ensure the recovery of the remaining inoculum.

Combination pre- and postpackage surface pasteurization. We investigated a combination pasteurization process that included a short prepackage pasteurization treatment (for 45 or 60 s) followed quickly by vacuum packaging and postpackage pasteurization (for 45, 60, or 90 s) by submersion and subsequent microbial analysis as described previously (7).

Product temperature measurement. Product temperatures were measured by several methods. Temperature-hardened DataTrace probes (Mesa Labs, Lakewood, Colo.) were placed at the tops, bottoms (offset to one side), sides, fronts, and backs of turkey bologna samples to determine the oven's temperature distribution on all sides of the product, which could not easily be determined by any other method (Fig. 1C). An infrared digital thermometer (Raynger Model ST80, Raytek, Santa Cruz, Calif.) that could provide the average, minimum, and maximum temperatures of the locations of eight infrared dots projected onto a product in a circular pattern was also used (Fig. 1D).

Microbiological analysis. For the recovery of the inoculum bacteria remaining after radiant heat and/or postpackage pasteurization, products were placed into large sterile bags, and 25 to 50 ml of buffered peptone water was added. The bags were then shaken and massaged for 5 min to resuspend surviving bacteria in the rinse buffer. Recovery of the rinse buffer was followed by appropriate serial dilutions and pour plating on TSA containing the antibiotics specified above. The plates were then incubated for 48 h at 30°C.

Experimental design. Except for one trial involving frozenand-thawed roast beef that was carried out in duplicate, all trials were carried out in triplicate. Inoculated control samples and experimental samples were run in pairs for each processing condition within a replicate. Different replications were carried out on separate days with different lots of the same product and with pairs of samples from the same lot for each test condition. Standard deviations were obtained for multiple samples in the various replications. Treatment times were limited to those of practical application by the various participating processors.

## RESULTS AND DISCUSSION

In this study, we examined prepackage surface pasteurization of RTE meats with the use of a radiant heat oven (Fig. 1A and 1B) alone and in combination with postpackage pasteurization (7) for the reduction of incidental *L. monocytogenes* contamination that could occur during postprocessing handling and packaging.

We examined the surface temperatures of a turkey bologna product with temperature-hardened probes. With the use of paired placements of probes (Fig. 1C) on turkey bologna (top-offset-bottom, left side-right side, front facerear face) we were able to examine the temperatures on the various surfaces in order to test for major discrepancies. The largest discrepancy observed was that between the upper and lower product surface temperatures (Fig. 2A), which was a result of the "shielding" of the bottom of the product by the stainless steel mesh conveyor belt and was alleviated (Fig. 2B) by a design modification. In order to alleviate this condition, the manufacturer suggested making 1626 GANDE AND MURIANA J. Food Prot., Vol. 66, No. 9

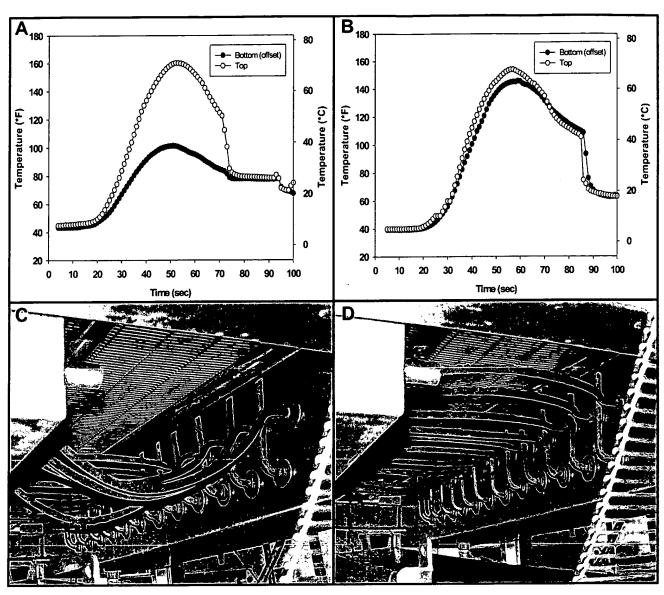


FIGURE 2. Temperature profiles obtained from turkey bologna with temperature-hardened DataTrace probes placed on the top and on the bottom (offset from dead center) of the product in relation to the positioning of the underlying heating elements. Temperature profiles with bottom heating elements (A) turned down and away from the conveyor belt, (B) turned up toward the underside of the conveyor belt, (C) directed downward, and (D) directed upward toward the conveyor belt are shown. The radiant heat oven conditions included a 60-s treatment time, temperature setting no. 4, and an air temperature of 475°F (246°C).

a rotational adjustment to the heating coils underlying the conveyor belt (Fig. 2C) to move the coils closer to the belt and the overlying product's bottom surface (Fig. 2D). This modification resulted in a noticeable and significant improvement in the top and bottom heating profiles compared with what had previously been observed. It should be noted that the "bottom" probes were placed "off center" and were not influenced by the temperature of the belt, which is nominally 95 to 99°F (35 to 37°C) upon its return to the oven entrance, since approximately 65 to 70% of the circuit of the circular belt is outside the oven; this is also the case for larger commercial systems.

Although we used metal-tipped probes to obtain surface measurements, we recognized that these probes could be susceptible to errors. If the probes are placed 1 to 2 mm too deep (along the surface), they may measure more sub-

surface temperature, and if placed too high, they may be influenced more by air temperature, and therefore extreme care was taken in their placement. Our intention was to determine whether gross temperature differences existed, because we expected that different products of different shapes and sizes would be positioned closer to or farther from the upper heating coils in practical use, and this would present a problem with any fixed-distance radiant oven. A handheld infrared thermometer that gave the average temperatures at the locations of eight infrared dots projected onto the surface of a product (Fig. 1D) was also used. At first, this infrared thermometer appeared to be a better means of obtaining accurate surface temperature measurements. However, temperature values would change as either conveyor belt or hand movement would change the positions of the dots and the exact points that were being mea-

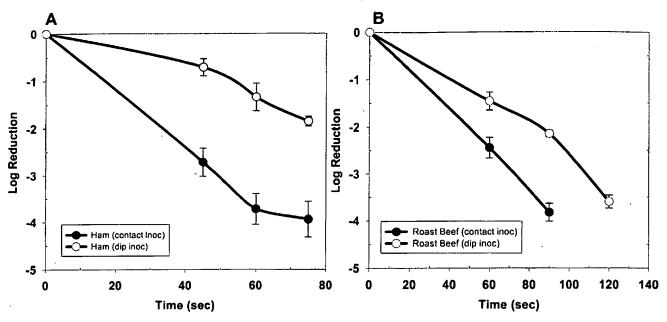


FIGURE 3. Radiant heat surface pasteurization of (A) ham and (B) roast beef inoculated by the dip method or the contact method and processed at highest power setting for the time indicated. Each data point represents the mean for paired samples from triplicate replications. Error bars represent standard deviations of the mean.

sured. It is conceivable that a mounted infrared temperature sensor-monitor could provide continuous monitoring of product as it exits the oven to provide a continuous realtime alert if targeted surface temperatures are not achieved (i.e., with the sensor-monitor pointing at the product, perhaps through a hole in the exit housing, as it exits the oven). With the handheld infrared monitor, we observed surface temperatures for ham in the ranges of 138 to 162°F (59 to 72°C; 30-s treatment time), 147 to 189°F (64 to 87°C; 45s treatment time), 154 to 209°F (68 to 98°C; 60-s treatment time), and 165 to 215°F (74 to 102°C; 75-s treatment time). Some cut meat surfaces (turkey bologna, roast beef half rounds) showed somewhat lower temperatures than other surfaces, either because the cut flat side was offset from directly facing the heat source or because the cut sides also showed slight sweating (purge) during heating. Occasionally, surface temperatures as high as 250°F (121°C) would be observed, but temperatures would quickly decrease as the product moved.

As with postpackage pasteurization, care should be taken in developing microbial-reduction processing models based on surface temperatures without confirmatory inoculation studies. It is clear from various high surface temperature measurements we obtained that the accompanying microbial reduction was not in line with what would be expected on the basis of extrapolation from D-values (decimal reduction times) for the inoculated pathogens (7). Unlike the heating of fully cooked products to a specific internal temperature so that the entire product from the center outward has reached at least the target temperature, brief surface heating may not necessarily penetrate all of the cuts, folds, and crevices that can be accessed by bacteria, and therefore single-point, or even multipoint, temperature readings for the outermost surface may be of limited practical application.

In previous studies of postpackage pasteurization, a fixed amount of inoculum was added to each of the products in vacuum-packaging bags before the bags were vacuum sealed (7). This method of inoculation had to be modified for use with surface inoculation of a nonpackaged product, and therefore we examined both a dip inoculation method and a contact inoculation method and contemplated the practical difference between the two methods after they had been used in several pasteurization trials. RTE deli ham and roast beef half rounds inoculated by both methods were surface pasteurized (Fig. 3). The results obtained indicate that L. monocytogenes reductions for the contact inoculation method were 1 to 2 log cycles larger than those for the extreme dip inoculation method. During the radiant heat surface pasteurization of hams inoculated with L. monocytogenes and processed for 45 to 75 s, we obtained 0.75- to 1.85-log reductions when the dip method was used and 2.7to 3.9-log reductions when the contact inoculation method was used (Fig. 3A). Similarly, with roast beef we achieved 1.5- to 2.2-log reductions for the dip inoculation method and 2.5- to 3.8-log reductions for the contact inoculation method when samples were processed for 60 to 90 s (Fig. 3B). The differences between the two inoculation methods are reasonably assumed to be due to the aggressive infiltration of small cracks, crevices, and folds, which protects some of the bacteria from the full heating regimen, when the dip method is used.

Our results indicate that radiant heat pasteurization can reduce incidental contamination that may be acquired upstream during postprocessing handling. We propose that this process would be most effective just prior to final packaging, a stage for which no such microbial interventions currently exist. However, there could still be concerns about contamination during the final packaging, although such contamination would be minimized if the product were

1628

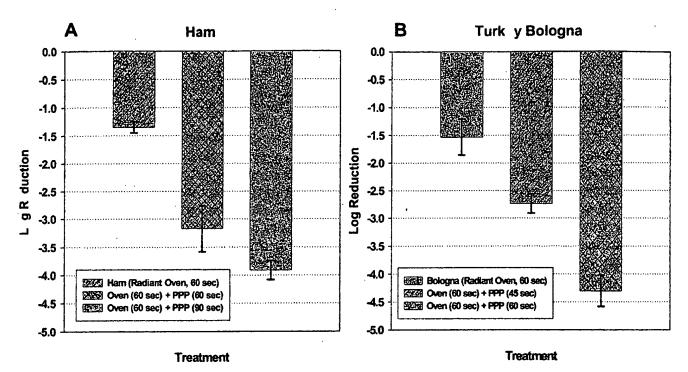


FIGURE 4. Radiant heat prepackage surface pasteurization of (A) formed ham and (B) turkey bologna alone and in combination with postpackage pasteurization. Prepackage pasteurization was performed at temperature setting no. 5 (the highest setting) for ham (for an air temperature of 750°F [399°C]) and at temperature setting no. 4 for bologna (475°F [246°C]) with a 60-s treatment time for both products. Postpackage pasteurization (PPP) was applied for 60 or 90 s for ham and for 45 or 60 s for turkey bologna at 200°F (93.3°C). Products were inoculated by the dip method.

packaged immediately while still hot. With this in mind, we further examined a combined pre- and postpackage pasteurization step that would provide the benefit of direct surface heating of prepackage pasteurization along with the added benefit of further pasteurization after the final packaging while the surface is still warm (at which point no further exposure to contamination due to handling would occur). For formed ham and turkey bologna, we obtained 1.35- and 1.53-log reductions of L. monocytogenes, respectively, when a 60-s radiant heat surface pasteurization step was used with product inoculated by dip method, our most aggressive inoculation method (Fig. 4). When prepackage pasteurization of the ham was followed by 60- or 90-s postpackage pasteurization at 200°F (93.3°C), we obtained overall 3.17- and 3.91-log reductions of L. monocytogenes, respectively (Fig. 4A). When prepackage pasteurization of the turkey bologna was followed by 45- or 60-s submersed water postpackage pasteurization, we obtained overall 2.73and 4.3-log reductions of L. monocytogenes, respectively (Fig. 4B).

The results of our examination of both the dip and the contact inoculation methods suggest that the contact inoculation method is more typical of the manner in which incidental contamination is acquired in plants and that this method is more practical for the surface inoculation of large nonpackaged deli meat products. It is important to note that the contact inoculation method does not undercut the safety of process evaluation, since the typical sponge-delivered contact inoculum for our deli products resulted in *L. monocytogenes* levels of ca. 10<sup>9</sup> CFU per product piece tested, and all products were inoculated in this manner on several

sides. There is no conceivable way that fully cooked product could acquire such high levels of *Listeria* through contact unless growth-permissive conditions were involved.

In an additional roast beef study involving only contact inoculation, we examined the effect of radiant heat surface pasteurization on whole and half rounds of roast beef positioned in the oven with the cut side facing either forward or to the side, and we compared frozen-and-thawed roast beef product processed by radiant heat pasteurization alone with that processed by radiant heat pasteurization in combination with postpackage pasteurization (Fig. 5). Radiant heat pasteurization of both whole and half rounds of fresh refrigerated roast beef (regardless of position) as well as whole logs of corned beef resulted in similar L. monocytogenes reduction levels (2.15 to 2.45 log cycles) (Fig. 5A). However, radiant heat pasteurization of frozen-and-thawed roast beef resulted in lower reduction levels (1.5 log cycles), presumably owing to the destruction of meat cells, leading to an increase in the "juiciness" of the roast beef after thawing (Fig. 5B). When frozen-and-thawed roast beef was processed via short-term postpackage pasteurization (for 60 and 90 s), freezing and thawing together with the short processing time was also found to result in low L. monocytogenes reduction levels (Fig. 5B). However, whether roast beef was fresh, or frozen and thawed, the use of the combination of 60 s of radiant heat pasteurization followed by 60 or 90 s of postpackage pasteurization (200°F) resulted in reduction levels of >3 log cycles (Fig. 5A and 5B), which would have required 10 min to achieve with postpackage pasteurization alone. It should be noted that for fresh roast beef, the combination of 60 s of radiant heat

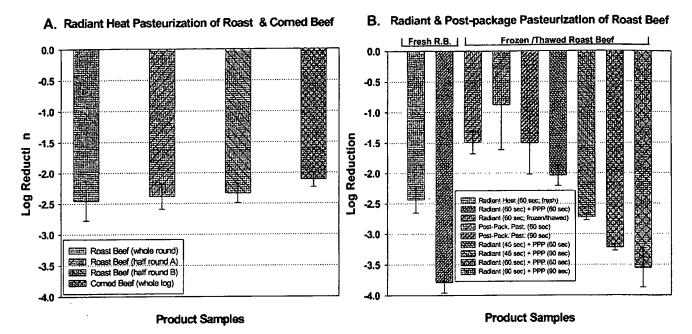


FIGURE 5. Radiant heat prepackage pasteurization of roast beef alone and in combination with postpackage pasteurization. (A) Radiant heat surface pasteurization of roast beef top rounds (whole round, 13 to 16 lb), half rounds with the cut sides facing the tunnel exit ("A," 6.5 to 8 lb), half rounds with the cut sides facing to the side ("B," 6.5 to 8 lb), and corned beef logs (whole, 25 to 27 lb). (B) Radiant heat surface pasteurization alone, submerged water postpackage pasteurization (PPP) alone, and a combination of pre- and postpackage surface pasteurization of roast beef half rounds. Treatments are as indicated. All of panel A and the first two bars of panel B represent fresh refrigerated product; the remainder of panel B represents product that was frozen and then thawed for testing. All samples were inoculated by the contact inoculation method.

pasteurization and 60 s of postpackage pasteurization resulted in larger reductions than a slightly longer process (60 s of radiant heat pasteurization and 90 s of postpackage pasteurization) did for frozen-and-thawed roast beef (Fig. 5B). The reduction in the time required for the postpackage pasteurization phase of the combination process (60 or 90 s) provided the additional benefit of generating little or no purge compared with what we have observed in trials involving longer postpackage pasteurization times (4, 6, 8, and 10 min) (7). These data demonstrate the effectiveness of a short-duration combined process that provides additional processing after final packaging with no further handling of the product in significantly reducing pathogen levels. However, the heat-treated product may need to be chilled prior to boxing, since the surface quarter inch has been heated.

The results of the present study indicate that radiant heat prepackage surface pasteurization, postpackage surface pasteurization (7), or a combination of the two processes can alleviate potential Listeria contamination on RTE deli meat surfaces with minimal effects on product quality. The benefits of such a process should be considered with respect to the potential for a product's acquisition of contamination in plant environments in which RTE products are manufactured and packaged and in comparison with those of preexisting processing lines that do not include additional intervention steps. The potential savings of such a process must be measured in view of recent large recalls (and, worse, illnesses and deaths) that have been attributed to the manufacture and distribution of contaminated products. The data provided herein demonstrate that new processing strat-

egies and microbial interventions that can provide safe products for the benefit of consumers and processors alike are currently available.

## **ACKNOWLEDGMENTS**

Support for this research was provided in part by the Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla. We also thank Unitherm Foodsystems Inc., Stevison Ham Co., Vincent Giordano Corp., J. Freirich Co., Bar-S Foods Co., Sara Lee Corp., and Cargill Foods for technical discussions, products, and/or financial support of this research. We also thank William Robertson, Brad Jordan, Suparna Mitra, and Bill Quimby for assistance with the plating of samples.

## REFERENCES

- Centers for Disease Control and Prevention. 1998. Multistate outbreak of listeriosis, United States, 1998. Morb. Mortal. Wkly. Rep. 47:1085-1086.
- Centers for Disease Control and Prevention. 1999. Update: multistate outbreak of listeriosis, United States, 1998–1999. Morb. Mortal. Wkly. Rep. 47:1117–1118.
- Centers for Disease Control and Prevention. 2000. Multistate outbreak of listeriosis, United States, 2000. Morb. Mortal. Wkly. Rep. 49:1129-1130.
- Gill, C. O., and J. Bryant. 1997. Decontamination of carcasses by vacuum-hot water cleaning and steam pasteurizing during routine operations at a beef packing plant. *Meat Sci.* 47:267-276.
- Glass, K. A., D. A. Grandberg, A. L. Smith et al. 2002. Inhibition of *Listeria monocytogenes* by sodium diacetate and sodium lactate on wieners and cooked bratwurst. J. Food Prot. 65:116-123.
- McLauchlin, J. 1996. The relationship between *Listeria* and listeriosis. Food Control 7:187–193.
- Muriana, P. M., W. Quimby, C. A. Davidson, and J. Grooms. 2002. Post-package pasteurization of RTE deli meats by submersion heating for reduction of *Listeria monocytogenes*. J. Food Prot. 65:963–969.

- Murphy, R. Y., and M. E. Berrang. 2002. Thermal lethality of Salmonella senftenberg and Listeria innocua on fully cooked and vacuum packaged chicken breast strips during hot water pasteurization. J. Food Prot. 65:1561–1564.
- Nesbakken, T., G. Kapperud, and D. A. Caugant. 1996. Pathways of Listeria monocytogenes contamination in the meat processing industry. Int. J. Food Microbiol. 31:161-171.
- Norwood, D. E., and A. Gilmour. 1999. Adherence of Listeria monocytogenes strains to stainless steel coupons. J. Appl. Microbiol. 86: 576-582.
- Samelis, J., G. K. Bedie, J. N. Sofos, K. E. Belk, J. A. Scanga, and G. C. Smith. 2002. Control of *Listeria monocytogenes* with combined antimicrobials after postprocess contamination and extended storage of frankfurters at 40°C in vacuum packages. *J. Food Prot.* 65:299-307.
- 12. Samelis, J., and J. Metaxopoulos. 1999. Incidence and principle

- sources of *Listeria* spp. and *Listeria monocytogenes* contamination in processed meats and a meat processing plant. *Food Microbiol*. 16:465-477.
- Samelis, J., J. N. Sofos, M. L. Kain, J. A. Scanga, K. E. Belk, and G. C. Smith. 2001. Organic acids and their salts as dipping solutions to control Listeria monocytogenes inoculated following processing of sliced pork bologna stored at 4°C in vacuum packages. J. Food Sci. 64:1722-1729.
- Scanga, J. A., A. D. Grona, K. E. Belk, J. N. Sofos, G. R. Bellinger, and G. C. Smith. 2000. Microbiological contamination of raw beef trimmings and ground beef. *Meat Sci.* 56:145-152.
- Shank, F. R., E. L. Elliot, I. K. Wachsmuth, and M. E. Losikoff. 1996. US position on *Listeria monocytogenes* in foods. *Food Control* 7:229-234.
- Thayer, D., and G. Boyd. 1999. Irradiation and modified atmosphere packaging for the control of Listeria monocytogenes on turkey meat. J. Food Prot. 62:1136-1142.

# COMPLIANCE GUIDELINES TO CONTROL LISTERIA MONOCYTOGENES IN POST-LETHALITY EXPOSED READY-TO-EAT MEAT AND POULTRY PRODUCTS

## **Table of Contents**

- A. Requirements of the Final Rule
- B. Studies on Post-lethality Treatments
  - I. Steam Pasteurization and Hot Water Pasteurization
  - II. Pre-Package Pasteurization and Post-Package Surface Pasteurization
  - III. High Hydrostatic Pressure Technology
- C. Studies on the Use of Antimicrobial Agents
  - I. Addition of Lactates, Acetates, Diacetates to Meat Formulations
  - II. Growth Inhibitor Packaging
- D. Sanitation Guidelines for Listeria monocytogenes
  - I. General Procedures
  - II. <u>Determining the Effectiveness of Sanitation Standard Operating Procedures</u> (SOPs)
  - III. Traffic Control
  - IV. Employee Hygiene
  - V. Sanitizers
  - VI. Sources and Control of Listeria monocytogenes Contamination
  - VII. <u>Determining the Effectiveness of Sanitation Procedures (Testing for Listeria monocytogenes, Listeria spp. or Listeria –like organisms)</u>
- E. References

## A. Requirements of the Final Rule

<u>Listeria monocytogenes</u> is a pathogen that is widely distributed in the environment such as plant, soil, animal, water, dirt, dust, and silage. Because <u>L. monocytogenes</u> can be found in slaughter animals and in raw meat and poultry and other ingredients, it can be continuously introduced in the processing environment. The pathogen can crosscontaminate food contact surfaces, equipment, floors, drains, standing water and employees. In addition, the pathogen can grow in damp environments and can establish a niche and form biofilms in the processing environment that is difficult to eliminate during cleaning and sanitizing. Other characteristics of <u>L. monocytogenes</u> that makes it a formidable pathogen to control are its heat and salt tolerance and its ability to grow at refrigeration temperatures.

The lethality treatment received by processed ready-to-eat (RTE) meat and poultry products eliminate the pathogen, however products can be re-contaminated by exposure after the lethality treatment during peeling, slicing, repackaging, and other procedures. Several foodborne illnesses resulting in hospitalization, miscarriage and death have been linked to the consumption of deli meats and hotdogs containing L. monocytogenes. The cause of L. monocytogenes contamination in these outbreaks was traced to post-lethality exposure and contamination by the pathogen. Hot dogs and deli meats are examples of RTE meat and poultry products that receive a lethality treatment to eliminate pathogens, and are subsequently exposed to the environment during peeling, slicing, and repackaging operations. If L. monocytogenes is present in the equipment used for peeling, slicing or repackaging, the pathogen can be transferred to the product upon contact. Since RTE products are consumed without further cooking for safety, there is a possibility of the occurrence of foodborne illness.

RTE meat and poultry processing plants must include control programs for Listeria monocytogenes in their HACCP plan, Sanitation SOP or prerequisite programs to prevent its growth and proliferation in the plant environment and equipment, and crosscontamination of RTE products. The final rule for the control of Listeria monocytogenes include three alternative methods that establishments can use in the processing of RTE meat and poultry products during post-lethality exposure. These alternatives are based on different ways of controlling L. monocytogenes used in the processing of RTE products that are exposed to the environment after the lethality treatment. The risk for contamination by the pathogen increases from alternative 1 to 3, based on the control methods used by the establishment. Alternative 1 requires an establishment to apply a post-lethality treatment and an antimicrobial agent or process to control L. monocytogenes. Alternative 2 requires an establishment to apply either a post-lethality treatment or an antimicrobial agent or process. In alternative 3, the establishment does not apply any post-lethality treatment or antimicrobial agent or process, so it is required to have a sanitation program that includes testing food contact surfaces and holding product when tests turn out positive. An establishment must identify to which alternative their RTE product falls into based on its control program for L. monocytogenes. An establishment must apply the control methods required for the specific alternative in its

processing so it can qualify for the alternative. Each alternative has requirements that the establishment must comply to.

The compliance guidelines aim to help the establishment in its use of control methods for L. monocytogenes. Its purpose is to show establishments what the control methods used singly or in combination can achieve to prevent or eliminate L. monocytogenes contamination in the product during post-lethality exposure. Establishments can use the guidelines to determine control methods that are best suited to their processing. Some establishments may have instituted methods which they have verified to be effective in controlling the pathogen and may not need to change their methods to follow these guidelines. However, FSIS will make a determination on the effectiveness of the controls and establishment verification testing when deciding how FSIS will conduct verification in the establishment. These guidelines will be updated as necessary to include validated and other effective procedures as they become available.

### Alternative 1

Alternative 1 requires the use of post-lethality treatment (which maybe an antimicrobial agent) to reduce or eliminate <u>L. monocytogenes and</u> an antimicrobial agent or process to suppress or limit the growth of the pathogen. For RTE products that are cooked and then removed from their cooking bag and sliced, diced or repackaged, there is a risk of cross contamination from the equipment, conveyor belts and the environment. These products need to be aseptically processed and then repackaged under strict sanitary conditions to prevent contamination from <u>L. monocytogenes</u>. Post lethality treatments such as steam pasteurization, hot water pasteurization, radiant heating and high pressure processing have been developed to prevent or eliminate post-processing contamination by <u>L. monocytogenes</u>. RTE products where post-lethality treatments were shown by studies to be effective in reducing the level of <u>L. monocytogenes</u> are whole or formed ham, whole and split roast beef, turkey ham, chicken breast fillets and strips, and sliced ham, sliced turkey, and sliced roast beef.

Examples of antimicrobial agents shown to inhibit listerial growth are lactates, acetates or diacetates added in the formulation and the use of growth inhibitors in the immediate packaging material. Some growth inhibitor packaging and some levels and combinations of antimicrobial agents were shown by research studies to reduce the levels of <u>L. monocytogenes</u>. RTE products where studies on antimicrobial agents were shown to be effective in the control <u>L. monocytogenes</u> are hot dogs, bologna, cotto salami, and bratwurst.

An establishment whose product or process falls in Alternative 1 must have the post-lethality treatment that reduces or eliminates the pathogen in its HACCP plan. The post-lethality treatment must be validated according to § 417.4 as being effective in reducing or eliminating <u>L. monocytogenes</u> and the validation should specify the log reduction achieved by the post-lethality treatment and antimicrobial agents. The effectiveness of the post-lethality treatments and antimicrobial agents must be verified and have the verification results available to FSIS personnel upon request.

The antimicrobial agent or process that limits or suppresses <u>L. monocytogenes</u> must be included in the establishment's HACCP plan, or sanitation SOP, or other prerequisite program. The establishments must have documentation in its HACCP plan, Sanitation SOP or other prerequisite program to demonstrate that the antimicrobial agent or process, as used, is effective in suppressing or limiting growth of <u>L. monocytogenes</u>. The establishment must validate and verify the effectiveness of its antimicrobial agent or process included in its HACCP plan in accordance with § 417.4. If the antimicrobial agent or process is in the Sanitation SOP, the effectiveness of the measures must be evaluated in accordance with 416.14. If the control measures for <u>L. monocytogenes</u> are contained in a prerequisite program other than a Sanitation SOP, the program must ensure that the program is effective and does not cause the hazard analysis or the HACCP plan to be inadequate.

Post-lethality treatments can be applied as a pre-packaging treatment, e.g. radiant heating, or as post-packaging treatments, e.g., hot water pasteurization, steam pasteurization, and high pressure processing. Some of the studies on post-lethality treatments are reviewed in section B. Establishments should refer to the details of the studies if they want to use the intervention method in their processing. The guidelines will be updated to include studies or other methods as they become available. Studies on post-lethality treatments showed reductions of inoculated <u>L. monocytogenes</u> from 1 to 7 log<sub>10</sub> CFU/g depending on the product type, and duration, temperature and pressure of treatment. Higher log reductions were obtained when both pre-packaging and post-packaging surface pasteurizations were applied, and when post-lethality pasteurization was combined with the use of antimicrobial agents.

An establishment can use available published research studies as reference for their validation provided it uses the product type or size, the type of equipment, time, temperature, pressure and other variables used in the study in order to result in the same level of reduction of L. monocytogenes. An establishment that uses products, treatments or variables other than those used in the studies must perform its own validation studies to determine the effective reduction of L. monocytogenes as a result of the post-lethality treatment or antimicrobial agent applied to the products. Some of the published studies use different products and report a range of levels of reduction of L. monocytogenes. In this case, the establishment must validate the use of the post-lethality treatment or antimicrobial agent for their specific products. The establishment must specify the level of reduction achieved by the post-lethality treatment or antimicrobial agent applied in their validation. Aside from validation of the post-lethality treatment and antimicrobial agent, the establishment must verify its effectiveness by testing for L. monocytogenes.

Antimicrobial agents can be added to the product formulation, to the finished product or to the packaging material to inhibit growth of  $\underline{L}$ . monocytogenes in the post-lethality exposed product during its refrigerated shelf life. Studies on antimicrobials added to the packaging material or active packaging showed a 1-2  $\log_{10}$  CFU/g reduction of  $\underline{L}$ . monocytogenes during the refrigerated shelf life of the products. Lactates, acetates and diacetates are some antimicrobials added to the formulation of RTE meat and poultry

products. Based on published studies, growth reduction or inhibition achieved by adding these antimicrobials to product formulation depends on a variety of factors. Depending on the amount of antimicrobials and other growth inhibitors added to the product formulation and other ingredients in the product, growth inhibition of <u>L. monocytogenes</u> was shown to range from 30 days to 120 days at refrigerated temperatures. Some published studies on antimicrobials are reviewed in section C. Establishments should refer to the details of the studies if they want to use the intervention method in their processing.

An antimicrobial process that controls the growth of <u>L. monocytogenes</u> in the post-lethality environment is a lethality process that renders a RTE product shelf stable. Shelf stable products are formulated with salt, nitrites and other additives, and processed to achieve a water activity, pH and moisture-protein ratio that will reduce the level of <u>L. monocytogenes</u> and other pathogens during processing. In addition, the lethality treatment exerts a continuing bactericidal and bacteriostatic effect and does not support the growth of <u>L. monocytogenes</u> and other pathogens during the shelf life of the product at ambient temperatures. In this case, the antimicrobial process could serve as a both a post-lethality treatment and growth inhibitor. The establishment should have documentation on file to demonstrate the effectiveness of the lethality treatment through the shelf life of the product. Examples of shelf stable RTE products are country cured ham, pepperoni, salami, and jerky.

Another antimicrobial process that controls the growth of <u>L. monocytogenes</u> in the post-lethality environment is freezing of RTE products. Freezing prevents the growth of any microorganisms in the product because their metabolic activities are arrested, but depending on the method and length of freezing and other factors, some microbial kill can also result. Like other microorganisms, <u>L. monocytogenes</u> is resistant to freezing. Once the product is thawed, metabolic activities of microorganisms may resume, depending on whether the microorganisms are killed, injured, or not affected at all. Therefore this antimicrobial process is only effective while the product is frozen. Labels of RTE frozen products contain cooking instructions for the frozen product and for thawed and refrigerated product, and instructions for thawing at refrigerated temperatures. Examples of frozen RTE products are fully cooked frozen chicken nuggets, fully cooked frozen chicken breast patties or fully cooked frozen dinners.

The establishment can include the antimicrobial treatment that limits or suppresses <u>L. monocytogenes</u> in the HACCP plan, or Sanitation SOP or prerequisite program. However, the establishment must show the effectiveness of the antimicrobials in suppressing or limiting <u>L. monocytogenes</u> in these programs. An establishment can use published studies as reference for its validation as long as it uses the same treatment variables as those used in the study. These variables include among others, specific antimicrobial agents, concentration, time and temperature of effectiveness and others. Use of antimicrobial singly or in combination, with different concentration and other variables, and for products not used in the studies must be validated or tested for their effectiveness. This must be validated for the HACCP plan, or documented in the Sanitation SOP or other prerequisite programs. The establishment must verify that the

antimicrobial program is effective by testing product for <u>L. monocytogenes</u> and must verify that it does not cause the hazard analysis or the HACCP plan to be inadequate.

An establishment with products in Alternative 1 must maintain sanitation in the post-lethality processing environment in accordance with part 416. The establishment must make the verification results that demonstrate the effectiveness of its controls, whether from carrying out its HACCP plan, or its Sanitation SOP, or other prerequisite program, available upon request to FSIS inspection personnel.

Establishments have been using prerequisite programs before in their processing operations, and the Agency has recently accepted the use of prerequisite programs as an option in another policy. However, giving the establishment the option to include the antimicrobial agent or process in a prerequisite program in this rule is the first time prerequisite programs are recognized in codified regulations.

An establishment with products in Alternative 1 must have a post-lethality treatment that effectively reduce or eliminate <u>L. monocytogenes</u>, and an antimicrobial agent or process that suppresses any growth of the pathogen and extend the effect of the post-lethality treatment during the shelf life of the product. The Agency considers these treatments to be effective in controlling the pathogen to result in a safe RTE product. If an establishment has an effective Sanitation SOP, any contamination by <u>L. monocytogenes</u> would be very small, so the post-lethality treatment and the antimicrobial will be able to reduce or eliminate this contamination. If there is gross contamination, the effectiveness of the treatments may be reduced or negated. Therefore the Agency is relying on the establishment's Sanitation SOP to prevent contamination with <u>L. monocytogenes</u>, and the post-lethality treatment and antimicrobials to further reduce or eliminate the pathogen.

Because of this combination of controls, the Agency is not requiring establishments to have a testing program for food contact surfaces. However, the establishments can test food contact surfaces for L. monocytogenes, or its indicator organisms, Listeria spp. or Listeria-like organisms, to verify that their Sanitation SOP is effective. L. monocytogenes belongs to the Listeria group or genus of microorganisms, therefore a positive test for Listeria spp. or Listeria-like organisms would indicate the potential presence of the pathogen. If these specific indicator organisms test negative, this is indicative that L. monocytogenes is not present. Aerobic plate counts (APC), total plate counts (TPC), and coliforms are not appropriate indicator tests for L. monocytogenes. Results from these tests do not indicate the presence or absence of the pathogen. Guidelines on sanitation procedures and food contact surface testing for L. monocytogenes or its indicator organisms, Listeria spp. or Listeria-like organisms, are found in section D.

## Alternative 2

An establishment that identifies its products in Alternative 2 must apply either a post lethality treatment <u>or</u> an antimicrobial agent or process that controls the growth of <u>L. monocytogenes</u>. The establishment must have the post-lethality treatment in its HACCP plan and must be validated according to § 417.4 as being effective in reducing or

eliminating <u>L. monocytogenes</u> and should specify the log reduction achieved by the post-lethality treatment. The effectiveness of the post-lethality treatment must be verified by testing for <u>L. monocytogenes</u> and have the verification results available to FSIS personnel upon request. If an establishment has a product identified in Alternative 2 and uses a post lethality treatment to control <u>L. monocytogenes</u> in its product, it is not required to test food contact surfaces in the post-lethality environment. However, it can test food contact surfaces for <u>L. monocytogenes</u>, or its indicator organisms (<u>Listeria spp.</u> or <u>Listeria-like organisms</u>), or it could be subject to frequent verification testing by FSIS if it does not.

An establishment in Alternative 2 that only uses an antimicrobial agent or process to control L. monocytogenes in its product must have the agent or process included in the establishment's HACCP plan, or sanitation SOP, or other prerequisite program. The establishments should have documentation in its HACCP plan, Sanitation SOP or other prerequisite program to demonstrate that the antimicrobial agent or process, as used, is effective in suppressing or limiting growth of L. monocytogenes. The establishment should document the log levels of the pathogen that the antimicrobial agent or process can suppress and the length of time in days that the antimicrobial is effective. The establishment must validate and verify the effectiveness of its antimicrobial agent or process included in its HACCP plan in accordance with § 417.4.

If the antimicrobial agent or process is in the Sanitation SOP, the effectiveness of the measures must be evaluated in accordance with 416.14. If the control measures for <u>L. monocytogenes</u> are contained in a prerequisite program other than a Sanitation SOP, the program must ensure that the program is effective and does not cause the hazard analysis or the HACCP plan to be inadequate. The establishment should document its antimicrobial agent or process, its implementation and its verification results sufficiently in order to show that the HACCP plan is adequate in controlling the pathogen. The establishment must verify that the antimicrobials are effective by testing for <u>L. monocytogenes</u> and have the verification results whether from carrying out its HACCP plan, or its Sanitation SOP, or other prerequisite program, available upon request to FSIS inspection personnel.

If an establishment's product is in Alternative 2 and uses an antimicrobial agent or process that suppresses or limits the growth of <u>L. monocytogenes</u> in its product, it should maintain sanitation in the post-lethality environment in accordance with part 416. The sanitation program must include testing for food contact surfaces in the post-lethality environment to ensure that the surfaces are sanitary and free of <u>L. monocytogenes</u> or its indicator organisms (<u>Listeria spp. or Listeria-like organisms</u>). Studies on antimicrobials showed growth inhibition of <u>L. monocytogenes</u> if present at low levels of contamination during the shelf life of the RTE product. Antimicrobials were not shown to be effective at higher levels of contamination, so an effective sanitation program, which includes verification testing for food contact surfaces must be implemented at the same time that antimicrobials are used.

The sanitation program must provide for testing food contact surfaces in the post-lethality processing area to ensure that surfaces are sanitary and free of <u>l. monocytogenes</u> or its indicator organisms. It must include the frequency of testing and identify the size and location of the sample sites to be sampled. It should include an explanation of why the testing frequency is sufficient to ensure that effective control of <u>L. monocytogenes</u> or its indicator organisms is maintained. In addition, the establishment must identify the conditions under which the establishment will implement hold-and-test procedures following a positive test for <u>L. monocytogenes</u> or its indicator organisms. The product will be subject to FSIS verification testing, because the establishment is not relying on a post-lethality treatment to eliminate <u>L. monocytogenes</u>.

## Alternative 3

A post-lethality exposed product that does not use a post-lethality treatment or an antimicrobial agent or process to control the growth of <u>L. monocytogenes</u> fall under Alternative 3. An establishment producing this product must control the pathogen in its post-lethality processing environment through the use of sanitation control measures. Because the establishment is not relying upon a post-lethality treatment or an antimicrobial agent or process to control <u>L. monocytogenes</u>, the product will be subject to frequent FSIS verification testing. Examples of products in this alternative are fully cooked meat and poultry that are packaged and refrigerated such as hotdogs, deli meats, chicken nuggets, or chicken patties.

For this alternative, the establishment must maintain sanitation in the post-lethality processing environment in accordance with part 416. The sanitation program must provide for testing food contact surfaces in the post-lethality processing area to ensure that surfaces are sanitary and free of <u>L. monocytogenes</u> or its indicator organisms. The testing program should include the frequency of testing, identify the size and location of the sample sites and include an explanation of why the testing frequency is sufficient to ensure that effective control of <u>L. monocytogenes</u> or its indicator organisms is maintained. In addition, the establishment should identify the conditions under which the establishment will implement hold-and-test procedures following a positive test for <u>L. monocytogenes</u> or its indicator organisms on a food contact surface.

Moreover, an establishment that produces a deli product or a hotdog product must verify that the corrective actions that it takes with respect to sanitation after an initial positive test for <u>L. monocytogenes</u> or its indicator organisms on a food contact surface in the postlethality processing environment are effective. The corrective action must indicate steps that the establishment will take to clean and sanitize the suspected food contact surfaces to eliminate the contamination. The verification of the effectiveness of the corrective action can be shown by follow-up testing that includes a targeted test of the specific site on the food contact surface area that is the most likely source of contamination by the organism and other additional tests in the surrounding food contact surface area as necessary to ensure the effectiveness of the corrective actions. During this follow-up testing, if the establishment obtains a second positive test for <u>L. monocytogenes</u> or an indicator organism, the establishment must hold lots of product that may have become

contaminated by contact with the food contact surface until the establishment corrects the sanitation problem indicated by the test result.

Further, in order to be able to release into commerce the lots of product that may have become contaminated with <u>L. monocytogenes</u> from the food contact surface, the establishment must sample and test the lots for <u>L. monocytogenes</u> using a sampling method and frequency that will provide a level of statistical confidence that ensures that each lot is not adulterated with <u>L. monocytogenes</u>. If the product tests positive for <u>L. monocytogenes</u>, the product is considered adulterated and must be withheld from commerce. The establishment may destroy the held product, or rework the held product using a process that is destructive of <u>L. monocytogenes</u>. The establishment must document the results of the testing and the disposition of the product. An example of a hold-and test scenario can be found in section E-VIII.

An establishment with products in Alternative 3 is likely to be subject to more frequent verification testing by FSIS than an establishment with products in Alternative 1 or 2. This is because the products in Alternatives 1 and 2 are formulated and/or processed to reduce or eliminate <u>L. monocytogenes</u> or limit its growth in the RTE product and present a lower risk than products in Alternative 3 that do not have these interventions. Likewise, an establishment in Alternative 3 that produces deli meat or hotdog products is likely to be subject to more frequent verification testing than one that does not produce such products because deli and hotdog products were ranked as higher risks for <u>L.</u> monocytogenes contamination by the risk assessment.

## Labeling

Antimicrobial agents that are added to RTE products, either to the formulation or to the finished RTE product, and those that are included in the primary packaging material of RTE products are required to be included in the ingredients statement of the product label. In addition, establishments that use a post-lethality treatment or an antimicrobial validated to effectively eliminate or reduce L. monocytogenes, or suppress or limit its growth in the product can make claims or special statements on the labels of their products regarding the presence and purpose of use of the substances. The purpose of such claims is to inform consumers about measures taken by the processor to ensure the safety of the product and enable consumers to make informed purchase decisions. Such claims are voluntary, and may be of value to consumers especially those in groups most vulnerable to foodborne illness. Processors need to document their validation of these claims. An example of a statement that can be made is: "Potassium lactate added to prevent the growth of L. monocytogenes." All labeling claims and label changes to add such claims must be submitted for evaluation and approval to the FSIS Labeling and Consumer Protection Staff.

## **Estimates of Annual Production Volume**

An establishment that produces post-lethality exposed RTE products shall provide FSIS with estimates of annual production volume and related information (such as the establishment's testing program) for the types of meat and poultry products processed

under Alternatives 1, 2, or 3. The establishment needs to provide the information at least annually, or more often, as determined by the Administrator. The Agency regards production volume as a more important risk factor than establishment size and therefore needs these data so that it can target its resources on higher volume operations in its verification program. FSIS will develop sampling frequencies for the establishments and the products based on these data. The Agency will make the sampling frequency available to the establishments so that they will have an indication of how the risk of L. monocytogenes is tied to verification sampling.

The form by which to collect the data will be available to establishments in paper or electronic formats. An electronic form for this purpose will be available to the establishments at all times after the rule becomes effective.

#### **B. Studies on Post-lethality Treatments**

(Mention of trade marks or commercial names does not constitute endorsement by USDA)

#### I. Steam Pasteurization and Hot Water Pasteurization

Post processing contamination of RTE meat and poultry is mostly confined to the surface. Pasteurization by steam and hot water acts on the surface microbial contaminants by the action of heat. Studies on surface pasteurization using steam or hot water were shown to be effective in reducing this contamination.

Studies by Murphy et al. (2003a) showed that post-cook hot water pasteurization and steam pasteurization resulted in a 7 log<sub>10</sub> reduction of L. monocytogenes in inoculated vacuum packaged fully cooked sliced chicken. The reduction was effective when single packaged breast fillets, 227 g- package strips and 454 g-packaged strips were heat treated at 90 C in a continuous steam cooker or hot water cooker for 5, 25 and 35 minutes respectively. These investigators developed a model called ThermoPro that could predict the thermal lethality of pathogens in fully cooked meat and poultry products during postcook in-package pasteurization (Murphy et al., 2001, 2003b, 2003c). The model was developed using L. innocua and verified for L. monocytogenes.

#### TI. Pre-Package Pasteurization and Post-Package Surface Pasteurization

Muriana et. al., (2002) used a stainless steel water bath (similar to the Unitherm commercial Aquaflow food processor) to submerge cooked RTE deli-style whole or formed turkey, ham and roast beef, removed from their package, inoculated with L. monocytogenes and vacuum packaged. Results show a 2-4 log decrease in the levels of L. monocyogenes in inoculated products post-cooked at 195-205 F for 2-10 min.

Pre-package surface pasteurization treatment of the fully cooked meat removed from their packaging wrap and inoculated with L. monocytogenes resulted in a 1.25 to 3.5 log reduction with a treatment time of 60-120 s at 475 to 750 F air temperature (Gande and Muriana, 2003). Surface pasteurization was applied on cooked whole and split roast beef, whole corned beef, and whole and formed ham using a radiant oven ("Infrared Grill", Unitherm FoodSystems). Pre-package pasteurization (60 sec) combined with post-package submerged water pasteurization using formed ham (60 or 90 sec), turkey bologna (45 or 60 sec), and roast beef (60 or 90 sec), resulted in a 3.2 to 3.9 log reduction for ham, 2.7-4.3 log reduction for bologna, or a 2.0-3.75 log reduction for roast beef. The level of reduction varied depending on the method of inoculation, type of product used, treatment temperature, and residence time.

# III. High Hydrostatic Pressure Processing

High pressure processing (HPP) is one of the new technologies used for food processing. This technology provides a means of ensuring food safety for those products that are difficult to be heat treated due to organoleptic effects. HPP was shown to inactivate pathogens without any thermal or chemical effects and at the same time preserve the quality of the product. Raghubeer and Ting (2003) evaluated the efficacy of high hydrostatic pressure processing in inactivating L. monocytogenes in retail-packaged samples of sliced ham, turkey and roast beef obtained from a manufacturer and repackaged in 25-g portions. Results show that an inoculum of about 10<sup>4</sup> L. monocytogenes cocktail in these 3 products and HPP treatment at 87,000 psi for 3 minutes showed no recovery of L. monocytogenes after 61 days of storage at 34° F. There were no pressure-injured cells detected. There were no adverse organoleptic effects detected on the 3 HPP treated products during the 61-day shelf life study. No signs of spoilage were seen on all 3 products after 61 days of storage, and for 100 days for ham and turkey. According to the investigators, the normal shelf life of these products is 30 days, so the HPP treatment extended the shelf life of the products.

#### C. Studies On The Use of Antimicrobial Agents

# I. Addition of Lactates, Acetates, Diacetates to Meat Formulations

Studies have shown that lactic acid and acetic acid have significant antimicrobial activity in broth and food systems. Sodium and potassium salts of these acids, when added to processed meat formulation are also known to potentially inhibit pathogenic bacteria especially <u>L. monocytogenes</u>. These antimicrobials inhibit growth of pathogens by inhibiting their metabolic activities. Interest in these antimicrobials is in the growth inhibition of L. monocytogenes in post lethality exposed RTE meat and poultry products.

FSIS recently increased the permissible levels of sodium acetate as a flavor enhancer in meat and poultry products, and of sodium diacetate as a flavor enhancer and as an inhibitor of pathogen growth to 0.25 %(65 FR 3121-3123/2000). The rule also permitted the use of sodium lactate and potassium lactate in meat and poultry products at 3 %, corresponding to a 4.8 % of the 60 % commercial product (except for infant formulas and infant food) for the purposes of inhibiting the growth of certain pathogens. The addition of antimicrobials in the formulation must be included in the ingredient statement of the label. Several studies used these antimicrobials to show their ability to inhibit growth of L. monocytogenes in different meat formulations.

Seman et al., (2002) developed a mathematical model capable of predicting the growth or stasis of <u>L. monocytogenes</u> in commercial cured meat products using a response surface method. The model can be used by manufacturers in the determination of the appropriate amounts of potassium lactate and sodium diacetate to be added to cured meat products that are organoleptically sensible and will not support the growth of <u>L. monocytogenes</u>. Thirty products were formulated by using a variety of raw material sources such as pork trimmings, trimmed turkey breast halves and four-muscle ham. Varying amounts of potassium lactate and sodium diacetate were added to the meat formulation and the meats were processed into different products. After chilling, the products were stripped of their casings, sliced into 25-g slices, placed into pouches, and inoculated with <u>L.</u> monocytogenes by applying to the surface of 100g of cured meat (four slices).

The results show that increasing amounts of potassium lactate syrup and sodium acetate decreased the growth rate of <u>L. monocytogenes</u>, while increasing finished product moisture increased the growth rate. Sodium chloride content was not significant but was found to have a negative correlation to growth rate. The investigators provided final regression equation predicting the growth of <u>L. monocytogenes</u> in cured RTE meat products stored at 4° C. The investigators used predictive model performance factors and a simple linear regression analysis to evaluate the model generated in this study. They verified the accuracy of the model by comparing with actual <u>L. monocytogenes</u> growth data from independent challenge study conducted with for four different commercial RTE meat products using similar storage conditions. Performance factors calculated and evaluated for control products (those not containing potassium lactate and sodium diacetate) indicated that on the average, the predicted growth of <u>L. monocytogenes</u> exceeded those of the observed values by about 24 %.

This study provided a useful model in determining the target amounts of potassium lactate and sodium acetate for cured meat product formulations to inhibit the growth of <u>L. monocytogenes</u>. The calculations would also require knowledge of the finished product sodium chloride and moisture contents. The investigators advised that this validated model is specific to the products designed for the study and the <u>L. monocytogenes</u> strains used. Testing of this model in other environments and with other <u>Listeria</u> spp., and to formulations that are outside the model's limits may result in different maximum growth rates. This study was used as the basis for the Opti.Form <u>Listeria</u> Control Model.

The Opti.Form <u>Listeria</u> Control Model (PURAC) is a unique tool to calculate the levels of lactate and diacetate required to retard the growth of <u>Listeria monocytogenes</u> in cured meat and poultry products. The model is based on the study detailed in the paper by Seman et al, 2002, above. The model, which is available on CD-Rom includes:

- instructions on how to use the model
- explanation on the development of the model
- information on the anti-microbial effect of lactate and diacetate
- lactates and diacetates and use of these products
- regulations and labeling
- literature references

To receive a free copy of the model on CD-Rom, call: 888-899 8229, E-mail pam@purac.com

Bedie et al., (2001) evaluated the use of antimicrobials, included in frankfurter formulations, on <u>L. monocytogenes</u> populations during refrigerated storage. Fully cooked and cooled frankfurters were inoculated with 10<sup>3</sup> to 10<sup>4</sup> CFU /cm<sup>2</sup> of <u>L. monocytogenes</u> after peeling and before vacuum packaging. Samples were stored at 4° C for up to 120 days and sampled for testing on assigned days. Results are as follows:

ANTIMICROBIAL	LEVEL (%)	L. MONOCYTOGENES GROWTH INHIBITION	
Sodium lactate	3	70 days no pathogen growth	
Sodium diacetate	0.25	50 days no pathogen growth	
Sodium acetate	0.25, 0.50	20 days no pathogen growth	
Sodium lactate	6	120 days no growth and reduced pathogen growth	
Sodium diacetate	0.5	120 days no growth and reduced pathogen growth	
Control	0.0	Increased to 6 logs in 20 days	

No pathogen growth refers to no increase in the number of inoculated L.monocytogenes cells (bacteriostatic); while reduced pathogen growth refers to a decrease in the number of inoculated L. monocytogenes cells (bactericidal) in the product. In this study, tables showed the reduction varied with storage days, but was up to 1.0 log on some days. Antimicrobials were found to have no effect on pH except for sodium diacetate at 0.5 % which reduced the initial pH. Using the formulations and conditions in the study, establishments can add 3 % sodium lactate in the frankfurter formulation and obtain no growth of L. monocytogenes up to 70 days at refrigerated storage of 4° C. If the lethality treatment is adequate to eliminate L. monocytogenes, then the only probable source of L. monocytogenes would be from exposure of the product during peeling and repackaging. However, the establishment's sanitation program may keep the numbers to a very low level, and 3 % sodium lactate included in the formulation would inhibit the growth of L. monocytogenes during the product's refrigerated shelf life. Levels of sodium lactate at 6.0 % and sodium diacetate at 0.5 % showed a reduction of the pathogens, however these levels are above the permitted levels.

This study by Samelis et al., (2002) used similar treatments, processing and inoculation procedures and frankfurter formulations as the previous study described above. However, in this study combinations of antimicrobials were used, and in combination with hot water treatment. Hot water treatment involved immersion of frankfurters, with two product links in a package to 75 or 80° C for 60 s. Storage at 4° C shows:

TREATMENT	LEVELS	L. MONOCYTOGENES GROWTH
	(%)	INHIBITION
Sodium lactate	1.8	35-50 days no growth
Sodium lactate +	1.8	120 days no growth; 35-50 days growth
sodium acetate	0.25	reduction
Sodium lactate +	1.8	120 days no growth; 35-50 days growth
Sodium diacetate	0.25	reduction
Sodium lactate +	1.8	120 days no growth, 35-50 days growth
Glucuno-delta-	0.25	reduction
lactone	<u> </u>	
Hot water treatment		Inoc. population reduced by 0.4-0.9 log
$(80^{\circ} \text{ C}, 60 \text{ s}) +$		CFU/cm <sup>2</sup> , and
Sodium lactate	1.8	50-70 days growth reduction by 1.1-1.4 CFU/
		cm <sup>2</sup>
Hot water treatment		Increase in growth to about 6-8 logs in 50 days
(80° C, 60 s)		
Control, no		Increase in growth to about 6 logs in 20 days
treatment		and 8 logs thereafter up to 120 days

<sup>\*3 %</sup> of a 60 % (wt/wt) commercial solution.

Glass et. al., (2002) evaluated sodium lactate and sodium diacetate on wieners and cooked bratwurst containing both beef and pork supplied by a commercial manufacturer. Antimicrobial solutions used were sodium lactate and sodium diacetate singly or in combination at varying concentration. Wieners were repackaged in gas-impermeable pouches, then surface-inoculated with <u>L. monocytogenes</u> mixture on multiple areas of the surface of each link. Packages were vacuum-sealed and stored at 4.5° C for up to 60 days. Two types of cooked bratwurst from a commercial manufacturer were evaluated: bratwurst that was cured and naturally smoked and bratwurst that was uncured and unsmoked. Bratwurst was stored at 3 or 7° C for up to 84 days.

The surface treatment consisting of dipping wieners into solutions containing up to 6 % lactate and up to 3 % diacetate for 5 s did not delay pathogen growth, indicating that dipping wieners in the lactate/diacetate solutions is not an efficient way to apply the antimicrobials. However, the inclusion of lactates and diacetates in the formulation was found effective in inhibiting growth of <u>L. monocytogenes</u>. Results are as follows:

PRODUCT	Sodium Lastata (%)	Sodium	L. monocytogenes levels (CFU/pkg)
Bratwurst uncured, unsmoked	<u>Lactate (%)</u> 3.4	diacetate (%)	Growth delayed for 4-12 weeks at 7 and 3° C storage, respectively.
unsmoked	2.0	0.0	Growth delayed for 1-2 weeks at 7 and 3° C storage, respectively.
Bratwurst cured, smoked	3.4	0.1	Growth inhibited for 12 weeks at 7 and 3° C storage.
Silloked	0.0	0.0	Growth up to 1 log after 4 weeks at 7 and 3° C
Wieners	3.0	0.0	Growth inhibited for 60 days at 4.5° C
	1.0	0.1	Growth inhibited for 60 days at 4.5° C

Study by (Porto et al., 2002) used freshly processed peeled frankfurters in vacuum sealed packages obtained from a commercial manufacturer. Two formulations of links were used in the study: one with added 2 or 3 % potassium lactate and the other without added potassium lactate. Frankfurters were aseptically removed from their original package, repackaged, and inoculated with a mixture of <u>L. monocytogenes</u>. The packages were vacuum-sealed to 95 kPa and incubated at 4 and 10° C.

Results show that addition of 2 % or 3 % potassium lactate in frankfurters can appreciably enhance safety by inhibiting or delaying the growth of <u>L. monocytogenes</u> during storage at refrigeration or abused temperatures. The viability of the pathogen was influenced by pH, and the levels of lactate added, but not by the presence of indigenous lactic acid bacteria.

Potassium	Inoculum	Storage	<u>Days</u>	L. monocytogenes levels (CFU/package)
lactate (%)	CFU/pkg	temp °C)	<u>Storage</u>	
2.0	20	4	90	Remained at about 1.6 log
3.0	20	4	90	Remained at about 1.4 log
3.0	500	4	90	Remained at about 2.4 log
0.0	20	4	90	Increased to about 4.6 log
0.0	500	4	90	Increased to about 5.0 log
2.0	20	10	60	Remained at about 1.4 log
3.0	20	10	60	Remained at about 1.1 log
0.0	20	10	60 Increased to about 6.5 after 28 days,	
				declined to about 5.0 after 60 days
3.0	500	10	60	Remained at about 2.4
0.0	500	20	60	Increased to about 6.6 log after 40 days and
				declined to about 5.5 log after 60 days

#### II. Growth Inhibitor Packaging

Growth inhibitor packaging is an intervention, which delivers an active antibacterial agent to the surface of an encased sausage product. By incorporating this special coating onto the internal surface of cellulose casings, the antilisterial treatment is transferred to the surface of the processed meat/sausage during thermal processing. Upon removal of the casing, the treatment remains active on the meat surface, providing effective protection against inadvertent <u>Listeria</u> contamination during subsequent peeling, collating, and packaging processes. Growth inhibitor packaging used in conjunction with functional HACCP and Good Manufacturing Practices provides the industry with one more tool in their intervention strategy to control the risk of pathogen contamination in ready-to-eat meat and poultry products.

Studies on meat formulations for hot dogs using NOJAX® ALTM (Viskase) showed that use of the casings provide a lethality hurdle to the growth of Listeria monocytogenes, not just an inhibitory effect. The lethality impact is delivered within the first hours/days of the sausage/hot dog package life. This impact is dependent on many variables but is generally in the range of 1 – 2 log kill of L. monocytogenes at high levels of inoculation. This performance has been observed in challenge studies conducted on hot dogs drawn from commercial full-scale trials at a number of commercial processing plants. In high inoculation trials, NOJAX AL has been combined with conventional growth inhibiting additives, and as expected, the lethality impact is obtained and then maintained throughout the product life cycle. In these same trials, without growth inhibiting additives, this casing produces lethality but in several weeks the remaining L. monocytogenes begin to grow.

NOJAX AL is available in the U.S. having approval by both FDA and USDA for its key component, nisin. This GRAS component must be included in the ingredient statement via a label change request to the FSIS Labeling and Consumer Protection Staff. Because this is a naturally derived polypeptide, there are storage and use-by criteria that will have to be adhered to by the user for maximum benefit. Casing shelf-life is about 60-90days with a not to exceed 85° F.

This technology can be applied to most hot dogs and sausages that are encased in cellulosic casing. This casing intervention can be used in any instance were casing is used as a mold for processed meat and poultry during thermal processing. This would include cellulose, plastic, and possibly natural casing. As part of a manufacturer's decision to use this technology, benefits are: 1) no capital costs or new equipment; 2) no change in processing steps, plant reconfigurations or introduction of process bottlenecks—essentially processor transparent in all aspects of use except casing storage requirements; 3) no impact on flavor, texture, or package appearance, and 4) minor labeling change to ingredient statement.

Since this is a surface treatment, cost will be proportional to the surface to volume ratio of the product: the larger the sausage diameter, the lower the cost per pound. In general, economic analyses put the cost of this lethality intervention at about 2-3 cents per pound of finished product, with a mid-range target price of 2.5 cents per pound for a traditional 10-to-the-pound retail pack of hot dogs.

Janes et al., (2002) investigated the effect of nisin added to zein film coatings (Z) coated onto cooked ready-to-eat chicken against <u>L. monocytogenes</u>. Cooked chicken samples inoculated with <u>L. monocytogenes</u> were dipped into Z dissolved in propylene glycol or ethanol, with or without added nisin (1,000 IU/g) and/or 1 % calcium propionate and stored at 4 C or 8 C for 24 days. After 16 d at 4 C, <u>L. monocytogenes</u> was suppressed by 4.5 to 5 log CFU/g with zein film coatings with nisin. The most effective treatment in the study for controlling <u>L. monocytogenes</u> on the surface of ready-to-eat chicken was using edible zein film coatings containing nisin at a storage temperature of 4°C.

The use of film coatings in a processing plant would be to fully process the meat products then coat them with the films. Coating can be done by spraying or dipping the processed meat products and then allowing them to dry. Zein coatings on the meat products can be dried by circulating air around the meat product using a fan. Finally, the dried coated meat products can be packaged with the usual plastic film material and refrigerated. Nisin is presently not approved in the USA for use on ready-to-eat meat and poultry products, and this study has not been tested in commercial poultry processing conditions.

Some general observations from the published studies on antimicrobials:

- Lactates, acetates and diacetates were found more effective in inhibiting growth of <u>L. monocytogenes</u> when used in combination than when used singly.
- These antimicrobials were found more effective when used to the maximum allowable concentration. However, higher concentrations of antimicrobials used in the formulation may affect the sensory qualities of the product, such as flavor and texture, which would necessitate sensory evaluation of treated products.
- When used in combination, the amount needed to inhibit growth may be reduced.
- These antimicrobials were found to have listeriostatic activity more than listericidal activity, i.e. they prevent growth of the pathogen more than reduce the number of cells of the pathogen, and therefore may not be effective against gross contamination of a product. The establishment's sanitation program should control gross contamination of the processing environment and equipment. Addition of antimicrobials would be effective only as part of the overall HACCP strategy.
- Including these antimicrobials in the formulation was found to be more effective in inhibiting listerial growth than dipping products in solutions of antimicrobials.

- The antimicrobial activity of lactates and acetates when used singly or in combination is affected by the level of contamination of the meat product surface, and processing factors such as pH, moisture, water activity, fat, nitrite, salt content, time and temperature of storage, and packaging atmosphere.
- Application of the treatments used in these studies is limited to the formulations, products and treatments used in the studies. Applying these studies to other products and formulations may result in different rates of growth inhibition. Therefore the effectiveness of the antimicrobials used in these studies must be verified by the establishment for other processed meat products and other storage temperatures.
- Antimicrobials used in the formulation must have an effective antilisterial activity throughout the commercial shelf life of the product. Currently the targeted commercial shelf life of refrigerated cooked meat products in the U.S.A. is 75 to 90 days.
- Using post-packaging thermal treatments in addition to antimicrobials was found to increase the total antilisterial effects of the antimicrobials.
- These antimicrobials were found to be more effective in smoked products formulated with sodium nitrite, or in products stored at strict refrigeration temperatures.
- Use of these antimicrobials may be a cost effective antilisterial method that very small establishments can use.

#### D. Sanitation Guidelines for Listeria monocytogenes

Control of <u>L. monocytogenes</u> is a challenge to a processing plant's sanitation program. The pathogen can grow in a damp environment, attach to surfaces that come into contact with raw or finished product, establish a niche and form biofilms. The sanitation program should include cleaning and sanitizing procedures that have been proven effective for the particular operation, separation of raw and RTE processing areas, traffic control, employee hygiene, and equipment flow and design among others.

Proper and effective sanitation involves both cleaning and verifying that the cleaning and sanitizing was effective. This involves developing and implementing written sanitation standard operating procedures (Sanitation SOP's). Sanitation SOP's could be viewed as the first step to designing a total system, including the HACCP plan, that will prevent, eliminate, or reduce the likelihood of pathogenic bacteria from entering and harboring in the plant environment. The Sanitation SOP's as described in 9 CFR 416.12 through 416.16, give detailed mandatory requirements for developing and implementing the sanitation program, while 416.17 describes how FSIS will verify that each establishment is meeting the Sanitation SOP regulations. In brief, the regulations require the following:

- Development of Sanitation SOP's (416.12) Each establishment shall develop a written Sanitation SOP that describes all sanitation procedures to be performed each day, before and during operations with specific frequencies of each procedure and the responsible person for each task. It must also describe the cleaning process for all food contact surfaces, utensils, and equipment used to process your product(s). This document must be signed and dated by either the person responsible for the overall sanitation operations or a higher level employee in the establishment once it is implemented, and when any changes are made to the Sanitation SOP's.
- Implementation of SOP's (416.13) All preoperational procedures identified in the Sanitation SOP shall be done daily, before processing operations start. Each procedure must be performed at the specified frequency and they must be monitored daily.
- Maintenance of Sanitation SOP's (416.14) Each establishment shall routinely determine if the written Sanitation SOP is still effective in preventing direct product contamination and adulteration. If the Sanitation SOP is determined not to be effective because of changes in equipment, utensils, facility, operations, or personnel, changes in the procedures must be made to reflect changes.
- Corrective Action (416.15) The appropriate corrective action(s) shall be taken when it has been determined by FSIS or by an establishment employee that the written Sanitation SOP has failed to prevent direct product contamination or adulteration of your product(s).
- Recordkeeping Requirements (416.16) Daily records shall be maintained that describe how the sanitation activities were implemented and monitored, and all corrective actions; these records must be initialed and dated. Both computer records and paper records are appropriate however; additional controls may be needed to ensure the integrity of the electronic data.
- Agency Verification (416.17) FSIS will verify the effectiveness and adequacy of the written Sanitation SOP's to ensure that they meet all of the regulatory requirements. This will be done by reviewing all records, direct observations, and microbial testing as deemed necessary.

#### I. General Procedures

An example of equipment and processing room cleaning using eight steps is outlined below. Cleaning should be increased and intensified during periods of construction.

1. Remove waste material. Dry clean equipment, conveyor belts, tables, floors to remove meat particles and other solid debris. Some equipment such as slicers and dicers need to be disassembled so that parts can be cleaned thoroughly.

Equipment may need to be cleaned and sanitized again after re-assembly.

- 2. Wash and rinse floor.
- 3. Pre-rinse equipment (rinse in same direction as product flow). Pre-rinse with warm or cold water less than 140°F (hot water may coagulate proteins or "set soils").
- 4. Clean and scrub equipment. Always at least use the minimum contact time for the detergent/foam. Written instructions should be provided on the location of possible niches and the cleaning method to use. CAUTION: Live steam for cleaning is not acceptable.
- 5. Rinse equipment (rinse in same direction as product flow).
- 6. Visually inspect equipment (repeat steps 3 and 4 if not clean visually or by testing such as ATP bioluminescence).
- 7. Sanitize floor and then equipment to avoid contaminating equipment with aerosols from floor cleaning. Care should be taken in using high pressure hoses in cleaning the floor so that water won't splash on the already cleaned equipment. Hot water, at least 180°F, for about 10 seconds to sanitize equipment. Sanitizers (e.g., chlorine, quaternary ammonia, etc.) may be more effective than steam for L. monocytogenes control. If steam heating equipment in an oven or tarp, the target internal temperature is 160° F and hold for 20-30 min. Portable high-pressure, low volume cleaning equipment (131°F (55°C) with 20-85 kg/cm² pressure and 6-16 liters/minute) can be used.
- 8. Remove excess moisture. This can be done most safely and efficiently by drying. Reduced relative humidity can speed the process. Avoid any possible cross-contamination from aerosol or splash if a method other than air drying is used. If cross-contamination is suspected, repeat steps 4-7.

# II. Determining the Effectiveness of Sanitation Standard Operating Procedures (Sanitation SOPs)

The establishment should determine if the cleaning and sanitizing procedures used was effective by visual examination or testing or both.

- 1) Visual inspection of the equipment and environment. Visual inspection is the minimum means of determining the effectiveness of the sanitation standard operating procedures (SOPs). It can only detect observable contamination.
  - a. Visually verify that no meat or product residue is on the equipment, especially those product contact surfaces and areas that may serve as niches for bacteria,

before the start of operation.

- b. Record the results of the visual inspection.
- c. If any residue is noted, corrective action should be taken and recorded.
- d. The monitoring record should be designed to show any trends of insanitary conditions. For example, if corrective action had to be taken on the first two days of operation for more than a week, this indicates a possible problem with cleaning and would have to be investigated to determine the source of the problem (e.g., improperly trained crew on those days, types of products processed).
- e. Visually verify that no meat or product residue is on the equipment, especially those product contact surfaces and areas that may serve as niches for bacteria, after post-processing cleanup.
- 2) Visual inspection and use of ATP bioluminescence testing. Visual verification combined with ATP testing can determine both observable contamination and contamination from bacteria and meat/poultry residues that may not be visually detectable. The combined methods are more effective in determining the effectiveness of the sanitation SOP.
- a. The ATP test indicates the presence of both bacteria and meat or poultry residues and can be used to verify that no meat or poultry residue is on the equipment, esp. those product contact surfaces and areas that may serve as niches for bacteria, before the start of operation.
- b. Record the results of the ATP test and visual inspection.
- c. If any residue is noted or observed visually or the ATP test indicates an insanitary condition, corrective action should be taken and recorded.
- d. The monitoring record should be designed to show any trends of insanitary conditions. For example, if corrective action had to be taken on the first two days of operation for more than a week, this indicates a possible problem with cleaning and would have to be investigated to determine the source of the problem (e.g., improperly trained crew on those days, types of products processed).
- e. By ATP testing and visual examination, verify that no meat or product residue is on the equipment, esp. those product contact surfaces and areas that may serve as niches for bacteria, at the end of the shift.
- 3) Visual inspection and total plate counts (TPC). Visual verification combined with TPC can determine both observable contamination and the level of bacterial contamination. Since TPC results cannot be obtained at the time of inspection, its value is the measurement of the level of contamination. The level of contamination may assist the

establishment in determining the source of contamination and the effectiveness of the sanitation SOP.

- a. Visually verify that no meat or product residue is on the equipment, esp. those product contact surfaces and areas that may serve as niches for bacteria, before the start of operation.
- b. Use swabs or RODAC plates for sampling food contact surfaces, non-food contact surfaces, and the processing environment.
- c. Record the results of the visual inspection.
- d. If any residue is noted, corrective action should be taken and recorded.
- e. Record the TPC when analysis complete.
- f. The monitoring record should be designed to show any trends of insanitary conditions as determined by visual inspection or TPC. For example, if corrective action had to be taken on the first two days of operation for more than a week, this indicates a possible problem with cleaning and would have to be investigated to determine the source of the problem (e.g., improperly trained crew on those days, types of products processed).
- g. Visually verify that no meat or product residue is on the equipment, especially those product contact surfaces and areas that may serve as niches for bacteria, again after post-processing cleanup.

#### III. Traffic Control

Controlling the movement of personnel and raw and finished products will help prevent cross-contamination of finished products by raw materials and personnel. The following are steps that should be taken for traffic control:

- 1. Establish traffic patterns to eliminate movement of personnel, meat containers, meat, ingredients, pallets and refuse containers between raw and finished product areas.
- 2. Control traffic into and within the RTE areas
  - a. If possible, use air locks between raw and RTE areas.
  - b. Clean dry floors are preferable to foot baths.
  - c. If foot baths are used:
    - i) Wear rubber or other non-porous boots.

- ii) Maintain them properly.
- iii) Solutions should contain stronger concentrations of sanitizer than normally used on equipment.
  - (1) For example, 200 ppm iodophor, 400-800 ppm quaternary ammonia compound).
  - (2) CAUTION: Chlorine is not recommended as it is too quickly inactivated esp. if cleated boots are used. Monitor and maintain its strength if used.
- iv) Use a minimum depth of 2 inches.
- d. Foam disinfectant spray on floor as people or rolling stock enter the room.
- 3. Employees should not work in both raw and RTE areas, if possible. If they must work in both areas, they must change outer and other soiled clothing, wash and sanitize hands, and clean and sanitize footwear.
  - a. Use different color smocks or helmets for raw and RTE areas so the workers and garments in the raw and RTE areas are readily distinguishable.
  - b. Remove outer garments (e.g., smocks) when leaving RTE areas.
- 4. Do not allow employees who clean utensils and equipment for raw materials to clean RTE utensils and equipment, if possible. If not possible, there should be a time separation when utensils for raw processing/handling are cleaned after RTE. The tools to clean utensils and equipment for raw materials must be different than those used to clean RTE utensils and equipment.
- 5. Do not permit maintenance employees in RTE areas during operations if possible. If not possible:
  - a. Consider the need to cease operations until a full cleaning and sanitizing is done, or,
  - b. Maintenance personnel must change outer clothing and any other soiled clothing, use separate tools for raw and RTE areas (or wash and sanitize tools and hands prior to entering RTE areas) and wear only freshly cleaned/sanitized footwear in such areas.
- Use separate equipment, maintenance tools and utensils for the RTE and raw areas. If
  not possible, there should be a time separation between raw processing/handling and
  RTE processing.

- 7. Pallets can serve as a source of cross-contamination pallets for raw materials should not be used in RTE areas or used for finished product.
- 8. Drains from the "dirty" or "raw" side should not be connected to those on the "clean" or "cooked" side.

#### IV. Employee Hygiene

Employee hygiene is the responsibility of both the individual and management. The employee is responsible for preventing contamination of food products and the management is responsible for ensuring the employee is properly trained and maintains good practices.

Employee responsibilities and actions should include:

- 1. Use a 20 second hand wash after using restroom facilities.
- 2. Wash hands before entering the work area, when leaving work area, and before handling product.
- 3. If gloves are worn:
  - a. Gloves that handle RTE product must be disposable.
  - b. Dispose immediately and replace if anything other than product and food contact surface is touched.
  - c. Dispose of gloves when leaving the processing line.
- 4. Remove outer clothing when leaving RTE areas.
- 5. Do not wear RTE clothing inside bathrooms or cafeterias.
- 6. Do not store soiled garments in lockers.
- 7. Do not eat in the locker room or store food in lockers.
- 8. Do not store operator hand tools in personal lockers. This equipment must remain in the RTE area at all times.

Management responsibilities should include:

- 1. Providing hand washing facilities at proper locations.
- 2. Ensuring the employee receives proper hygiene instruction before starting use of hand soaps and sanitizers, no-touch dispensing systems, and boot and doorway

sanitizing systems.

- 3. Developing a system for monitoring employee hygiene practices.
- 4. Developing a system for tracking the training, tests taken, and certification.
- 5. Retraining employees before placing back into production.

#### V. Sanitizers

Cleaning and sanitizing are vital to any effective sanitation program. Through cleaning should be followed by sanitizing. Generally, the cleaning step is to remove all waste materials and soils, and the sanitizing step is to destroy all microorganisms. Careful consideration should be given to selecting both, cleaning and sanitizing solutions. It is important to use solutions that are compatible with the equipment materials, such as stainless steel or heavy plastics, and solutions that are effective in destroying the type of bacteria commonly associated with the type of products you produce. Acidic quaternary ammonia, chlorine dioxide, and peracetic acid compounds were found to be the most effective in destroying attached organisms (Krysinski, L.J., et al;1992).

To aid the cleaning and sanitizing employee in properly selecting and applying the product for its intended application, products that are specifically designed to clean soils in meat and poultry establishments and that are color coded for each application should be selected. An example of this kind of product is Quorum (Ecolab, Inc., St. Paul., MN). Another help for the cleaning employee is to select products with product label and instructions written in English and Spanish.

# VI. Sources and Control of Listeria monocytogenes Contamination

<u>Listeria monocytogenes</u> is constantly introduced into the processing environment. It may be introduced in incoming raw product, processing environment or by employees. The following are steps that should be taken to prevent contamination of product with <u>L. monocytogenes</u> after cooking:

- Verify that cooking or other control measures will eliminate <u>L. monocytogenes</u>. Most meat products implicated in human listeriosis are contaminated with <u>L. monocytogenes</u> after these measures are applied. Undercooked product may introduce <u>L. monocytogenes</u> to food contact surfaces or the environment after cooking and before packaging.
- 2. Prevent contamination of product contact surfaces and prevent the formation and growth of <u>L. monocytogenes</u> in a niche, especially in areas after the cooking step. A niche is a harborage site within the plant that provides an ideal place for <u>L. monocytogenes</u> to establish and multiply. Certain strains can become established in a processing environment for months or years. L. monocytogenes can be spread from

these sites and re-contaminate food or food contact surfaces between the cooking step and packaging.

# Examples of reservoirs and harborages of <u>L. monocytogenes</u> in RTE processing environment

Hollow rollers on conveyors

On-off valves and switches

Worn or cracked rubber seals around doors

Vacuum/air pressure pumps, lines, hoses

Cracked tubular rods on equipment

Air filters

**Drains** 

Condensate from refrigeration unit

Floors

Standing water

Open or gulley drains

Ceilings and over head pipes

Overhead rails and trolleys

Chiller and passageway walls and doors

Chiller shelving

Roller guards

Door handles

**Boots** 

Ice makers

Saturated Insulation

Trolley and forklifts

Compressed air in-line air filters

Trash cans

Cracked hoses

Wet rusting or hollow framework

Walls that are cracked, pitted, or covered with inadequately sealed surface panels

Maintenance and cleaning tools

Space between close fitting metal-to-plastic parts

Space between close fitting metal-to-metal parts

3. Examine routes taken by products from heat treatment, or other control to eliminate L. monocytogenes, to final packaging.

### Typical sites of L. monocytogenes contamination

Filling or packaging equipment

Solutions used in chilling food

Peeler, slicer, shredders, blenders, brine chill, casing removal system, scales, or other equipment used after heating and before packaging

Spiral or blast freezers

Conveyors

Bins, tubs, or other containers used to hold food for further processing

- 4. Frequently clean sites known to support <u>L. monocytogenes</u> using effective cleaning procedures. The following is a recommended frequency for cleaning and sanitizing processing equipment and the plant environment:
  - a. Daily
    - i. All processing equipment
    - ii. Floors and drains
    - iii. Waste containers
    - iv. Storage areas
  - b. Weekly
    - i. Walls
  - c. Weekly/monthly
    - i. Condensate drip
    - ii. Coolers
  - d. Semiannually
    - i. Freezers
- 5. Maintain equipment and repair parts or machinery in a manner to prevent food deposits that are not easily removed with normal cleaning.
- 6. Implement a microbial sampling program to monitor and detect sources of <u>L</u>. monocytogenes in the environment. Environmental testing is more effective then product testing alone to monitor and detect <u>Listeria</u> in the environment.

- 7. Design a sampling scheme to locate a niche before <u>L. monocytogenes</u> becomes established.
  - a. Use a statistically designed sampling plans based on probability, or
  - b. Use prior experience and familiarity with processing conditions to determine the most likely source of contamination. All processing equipment would sampled but with a bias toward those areas identified as possibly problematic.
  - c. Review at least the last month of results to determine trends or to revise sampling scheme.
  - d. When a problem area is detected, take corrective action on the affected processing line as opposed to adjacent lines in the area. Target the area corresponding to the line associated with the findings for cleaning. Contamination is usually line specific.
- 8. Take follow up tests to monitor the area and verify the cleaning results.

#### Equipment Design

Selecting the appropriate equipment enhances cleaning operations and help control <u>L.</u> <u>monocytogenes</u> in the plant environment. The following are steps to take when selecting equipment:

- 1. If possible, develop a team (persons from Quality Assurance, Sanitation, Maintenance, and Production) to evaluate equipment before it is purchased or set specific requirements for plant equipment.
- 2. Have the equipment reviewed by a third-party expert if possible.
- 3. Select equipment designed to minimize sites on the exterior or interior where <u>L.</u> monocytogenes can grow.
- 4. Select equipment designed to enhance cleaning.
  - a. All areas and parts should be accessible for manual cleaning and inspection or be readily disassembled.
    - i. Closed conveyor designs are more difficult to clean. Equipment on the processing line should be as easy to clean as possible.
    - ii. Avoid hollow conveyor rollers and hollow framing. If hollow material is used, have a continuous weld seal instead of caulk.

- b. Equipment should be self-draining or self-emptying.
- 5. Select food contact surfaces that are inert, smooth and non-porous.
- 6. Maintain equipment and machinery by adopting regular maintenance schedules.
  - a. Damaged, pitted, corroded, and cracked equipment should be repaired or replaced.
    - i. Repair parts or machinery in a manner to prevent food deposits that are not easily removed with normal cleaning.
    - ii. Use separate tools for RTE equipment only. Sanitize them before and after each use.
  - b. If compressed air is used, maintain and replace in-line filters regularly.
  - c. Use lubricants that contain listericidal additives such as sodium benzoate. <u>L. monocytogenes</u> can grow in lubricants that are contaminated with food particles.
  - d. Use the appropriate cleaners and sanitizers on surfaces or equipment.

Thoroughly clean and sanitize equipment prior to using in production. Pathogens can live on surfaces that appear visually clean.

# VII. Determining the Effectiveness of Sanitation Procedures (Testing for <u>Listeria monocytogenes</u>, <u>Listeria spp. or Listeria</u>-like organisms)

Establishments can verify the effectiveness of their sanitation program by testing food contact surfaces (FCS) and other relevant environmental surfaces. This section includes recommended testing of food contact surfaces for each alternative, a guide to testing for <u>Listeria</u>-plike organisms, and an example of a hold and test scenario.

### A. Food Contact Surface and Environmental Testing

The sampling frequencies for FCS testing suggested below should be increased if there is construction, change in the HACCP plan, roof leaks, or other event that could change or increase the probability of product contamination. Samples should be taken at least 3 hours after the start of operation. Up to 5 samples may be composited. However, it is recommended that like surfaces be composited (e.g., food contact surfaces with other food contact surfaces, etc.). The sample locations for the composite sample should be noted to assist in determining the site of contamination. Environmental samples other than food contact surface samples should be taken by the establishment. This will also assist the establishment in locating potential sources of contamination.

- 1. Alternative 1 Use of a post-lethality treatment <u>and</u> an antimicrobial agent or process that limits growth of <u>L. monocytogenes</u>.
  - i) Conduct tests of food contact surfaces for <u>L. monocytogenes</u>, <u>Listeria</u> spp., or <u>Listeria</u>-like organisms at least twice a year.
  - ii) Sample at least 1 square foot area for each surface, if possible.
  - iii) Record the test results.
  - iv) If test results are positive for L. monocytogenes or Listeria-like or organisms:
    - (1) Take corrective action which should include an intensified cleaning and sanitizing.
    - (2) Record the corrective actions taken.
    - (3) Retest the food contact surface.
    - (4) Repeat corrective action and testing until samples are negative for <u>L.</u> monocytogenes or <u>Listeria</u>-like organisms.
    - (5) More than 3 consecutive positives should initiate intensified testing.
- 2. Alternative 2 Use of a post-lethality treatment <u>or</u> an antimicrobial agent or process that limits growth of <u>L. monocytogenes</u>.
  - i) If a post-lethality treatment is used, conduct tests of food contact surfaces for L. monocytogenes, Listeria spp., or Listeria-like organisms at least quarterly.
    - (1) Sample at least 1 square foot area for each surface, if possible.
    - (2) Record the test results.
    - (3) If test results are positive for <u>L. monocytogenes</u> or <u>Listeria</u>-like organisms:
      - (a) Take corrective action which should include an intensified cleaning and sanitizing.
      - (b) Record the corrective actions taken.
      - (c) Retest the food contact surface.

- (d) Repeat corrective action and testing until samples are negative for <u>L</u>. monocytogenes or <u>Listeria</u> spp., or <u>Listeria</u>-like organisms.
- ii) If an antimicrobial agent is used, conduct tests of food contact surfaces for <u>L.</u> monocytogenes, at least quarterly.
  - (1) Sample at least 1 square foot area for each surface, if possible.
  - (2) Record the test results.
  - (3) If 3 consecutive tests of food contact surfaces are positive for <u>Listeria</u> spp., or Listeria-like organisms:
    - (a) Take corrective action which should include an intensified cleaning and sanitizing.
    - (b) Record the corrective actions taken.
    - (c) Hold the product.
    - (d) Test product for <u>L. monocytogenes</u>.
    - (e) Retest the food contact surface.
    - (f) Repeat corrective action and testing until food contact surface test results are negative for <u>L. monocytogenes</u>, <u>Listeria</u> spp., or <u>Listeria</u>like organisms.
    - (g) If the test results for the product are positive for L. monocytogenes,
      - (i) Recall the product, if necessary, and
      - (ii) Destroy the product, or
      - (iii)Re-work the product with a process with a process that is destructive of <u>L. monocytogenes</u>.
- 3. Alternative 3 Use of sanitation control measures only to prevent contamination of product with <u>L. monocytogenes</u>.
  - i) Conduct tests for <u>L. monocytogenes</u>, <u>Listeria</u> spp., or <u>Listeria</u>-like organisms at least four times per month per line for large establishments, two times per month per line for small establishments, and once per month per line for very small establishments. (A large establishment is one that employs more than 500 employees, a small establishment is one that employs from 10 to 499

employees, and a very small establishment is one that employs less than 10 employees and one grossing less than \$ 2.5 million in sales.) FSIS regards production volume as a more important risk factor than establishment size and intends to use volume as one of the primary triggers for when considering its verification activity. For now, regarding deli meat and hotdog operations, FSIS is considering the break-off between high volume and low volume to be approximately 1.3 million pounds yearly, derived from the RTE survey.

- ii) Sample at least 1 square foot area for each surface, if possible.
- iii) Record the test results.
- iv) If the first test result of a food contact surface is positive for <u>Listeria</u> spp., <u>Listeria</u>-like organisms, record the corrective actions taken.
- v) For establishments producing hotdog or deli meat products, if the second test result of a food contact surface is positive for <u>Listeria</u> spp., <u>Listeria</u>-like organisms:
  - (1) Take corrective action which should include an intensified cleaning and sanitizing.
  - (2) Record the corrective actions taken.
  - (3) Hold the product or recall the product (see hold and test scenario below).
  - (4) Test for <u>L. monocytogenes</u> at a rate that provides a level of statistical confidence that the product is not adulterated.
  - (5) Retest the food contact surface each day until the test result is negative for <u>Listeria</u> spp., <u>Listeria</u>-like organisms.
  - (6) Continue to hold each day's production lot until the test results for the food contact surfaces are negative.
  - (7) If the test results for the product are positive for L. monocytogenes,
    - (a) Recall the product, if necessary, and
    - (b) Destroy the product, or
    - (c) Re-work the product with a process with a process that is destructive of L. monocytogenes.

- vi) For establishments producing products other than hotdogs or deli meats, if 3 consecutive tests of food contact surfaces are positive <u>Listeria</u> spp., or <u>Listeria</u>-like organism:
  - (a) Take corrective action, which should include an intensified cleaning and sanitizing.
  - (b) Record the corrective actions taken.
  - (c) Hold the product.
  - (d) Test product for L. monocytogenes.
  - (e) Retest the food contact surface.
  - (f) Repeat corrective action and testing until food contact surface test results are negative for <u>L. monocytogenes</u>, <u>Listeria</u> spp., or <u>Listeria</u>like organisms.
  - (g) If the test results for the product are positive for <u>L. monocytogenes</u>,
    - (i) Recall the product, if necessary, and
    - (ii) Destroy the product, or
    - (iii)Re-work the product with a process with a process that is destructive of <u>L. monocytogenes</u>.

FSIS realizes that some establishments' sanitation and testing program may be exceeding the guidance provided above. In this case, FSIS may put the establishment's product into a lower expected frequency for verification testing within the appropriate sampling frame under the following conditions:

- a) The establishment addresses major construction within its control program such that the intensity of sanitation and the verification testing procedures are increased during the time of the disruption and for a period of time following the disruption until the data demonstrate that there is no harborage of <u>L. monocytogenes</u> or its indicator organisms.
- b) The establishment has a good history of proper maintenance of the control program, particularly in regards to such things as the sanitation program, reacting to conditions that might indicate that harborage of <u>L. monocytogenes</u> or its indicator organisms is occurring, and appropriately reacting to positive test results for <u>L. monocytogenes</u> or indicator organisms.

B. Guidelines for <u>Listeria</u> spp. and <u>Listeria</u>-like testing for food contact surfaces and other environmental testing

<u>Listeria</u> spp. or <u>Listeria</u>-like organisms are the indicator organisms to be used for <u>L. monocytogenes</u> because their presence indicates the potential presence of the pathogen. If these specific indicator organisms test negative, this is indicative that <u>L. monocytogenes</u> is not present. Aerobic plate counts (APC), total plate counts (TPC), and coliforms are not appropriate indicator tests for <u>L. monocytogenes</u>. Results from these tests do not indicate the presence or absence of the pathogen. However, testing for these organisms can be done in addition to the testing for <u>L. monocytogenes</u> or its indicators to monitor the effectiveness of the cleaning procedures and level of contamination during processing. FSIS microbiology laboratory methods are available and can be downloaded at <a href="http://www.fsis.usda.gov/OPHS/microlab/mlgbook.htm">http://www.fsis.usda.gov/OPHS/microlab/mlgbook.htm</a>

# 1. Listeria spp. testing

- i) The methodology must employ enrichment prior to <u>Listeria</u> spp. screening.
- ii) <u>Listeria</u> spp. screening is conducted from the enrichment using an immunoassay, nucleic acid assay, or equivalent <u>Listeria</u> spp.-specific technology.
- iii) The above enrichment and screening must be part of a method in use by a government agency (i.e., FSIS or FDA) or validated by a recognized body (e.g., AOAC, AFNOR, ISO, etc.) for the detection of <u>Listeria</u> spp. and/or <u>L. monocytogenes</u>. Specific validation for environmental sampling is encouraged but not a requirement at this time.

#### 2. <u>Listeria</u>-like indicator testing

- i) The methodology must employ enrichment prior to <u>Listeria</u>-like indicator screening.
- ii) The <u>Listeria</u>-like indicator positive screening result may be indicated by the presence of suspect <u>Listeria</u> spp. colonies after selective plating, or may be indicated by biochemical changes to screening broths (*e.g.*, Fraser Broth) that are consistent with the potential presence of <u>Listeria</u> spp.
- iii) The above enrichment and screening must be part of a method in use by a government agency (i.e., FSIS or FDA) or validated by a recognized body (e.g., AOAC, AFNOR, ISO, etc.) for the detection of <u>Listeria</u> spp. and/or <u>L. monocytogenes</u>. Specific validation for environmental sampling is encouraged but not a requirement at this time.
- iv) Aerobic plate counts, ATP assays and other indicator organism tests that do not specifically meet the above requirements may be employed by the

establishment for supplemental sanitation testing. However, these tests do not meet the FSIS expectations for <u>Listeria</u> spp. or <u>Listeria</u>-like indicator food contact and other environmental surface testing programs that may be conducted by the establishment.

#### C. Hold and Test Scenario

Assuming it takes to 3 days to obtain a test result for <u>Listeria</u> spp., or <u>Listeria</u>-like organisms:

Day 1 – Take food contact surface (FCS) samples

Day 4 – FCS sample positive (from Day 1) for <u>Listeria spp.</u>, or <u>Listeria-like organisms</u>.

- ✓ Take Corrective Action
- ✓ Intensified cleaning and sanitizing
- ✓ Test FCS-- target most likely source of contamination, and additional tests in surrounding FCS area
- ✓ Continue production.

Day 7 – Second FCS sample (from Day 4) positive for <u>Listeria</u> spp., or <u>Listeria</u>-like organisms.

- ✓ Take Corrective Action
- ✓ Intensive cleaning and sanitizing
- ✓ Test FCS-- target most likely source of contamination, and additional tests in surrounding FCS area
- ✓ Hold and test product (for <u>L. monocytogenes</u>) for lot implicated in the positive FCS testing.
- ✓ Continue production, hold product from the day's production

#### Day 8 -

- ✓ Test FCS-- target most likely source of contamination, and additional tests in surrounding FCS area
- ✓ Hold product from this day's production

### Day 9 -

- ✓ Test FCS-- target most likely source of contamination, and additional tests in surrounding FCS area
- ✓ Hold product from this day's production

#### Day 10 -

If FCS sample (day 7 sample) is negative for <u>Listeria</u> spp., or <u>Listeria</u>-like organisms.

✓ Continue production and release product from days 7, 8 and 9 production

✓ Resume FCS testing according to frequency stated in sanitation program

If FCS sample (day 7 sample) is positive for <u>Listeria</u> spp., or <u>Listeria</u>-like organisms:

- ✓ Hold product from day 10 production.
- ✓ Test product from days 7, 8, 9, and 10 for <u>L. monocytogenes</u>
- ✓ Take corrective action
- ✓ Intensive cleaning and sanitizing
- ✓ Take FCS sample-- target most likely source of contamination, and additional tests in surrounding FCS area

Day  $14 - \text{If product is positive for } \underline{L. \text{ monocytogenes}}$ , do not release product to commerce and destroy product, or rework product with a process that is destructive of  $\underline{L.}$  monocytogenes.

Every time there is a second or more (consecutive) FCS positive, product is held and tested for <u>L. monocytogenes</u>. Only product lots implicated with a second or more consecutive FCS positive are held and tested. Every time there is a product positive for <u>L. monocytogenes</u>, product is recalled, if not held, and destroyed or reworked with a listericidal process. Once the FCS testing is negative, implying that the corrective action is working, production is continued.

Repeated FCS positives would imply a critical sanitation problem and the establishment need to conduct intensive testing and intensive cleaning and sanitizing. The establishment should have provisions in their FCS testing program for these kinds of situations.

#### D. Sentinel Site Program Example

Some establishments have adopted a sentinel site program for the control of  $\underline{L}$ .  $\underline{monocytogenes}$  in RTE meat and poultry products. A sentinel site program is similar to traditional  $\underline{Listeria}$  control programs – separate testing programs for the environment and food contact surfaces and increasingly aggressive corrective actions to eliminate  $\underline{Listeria}$  when it is detected. The distinctive characteristic of this control program is that in the case of a positive  $\underline{Listeria}$  test result for a food contact surface area, the sanitation of that particular area will be included in the HACCP plan as a CCP. The CCP is removed when the establishment determines that the food safety hazard has been eliminated and is not reasonably likely to occur.

The CCP is the sanitation program for the particular site and food contact surface sampling as verification of the CCP. If a food contact surface or non-food contact surface tests positive for <u>Listeria</u> spp. or <u>Listeria</u>-like organisms, testing is intensified in the area of the positive.

If a non-food contact surface sampling site is found to be positive for <u>Listeria</u> spp. or <u>Listeria</u>-like organisms during routine monitoring, intensified sampling is initiated as

soon as possible. Under intensified sampling, three samples per day (one each at pre-op, 1<sup>st</sup> shift, 2<sup>nd</sup> shift) are analyzed until a total of nine consecutive samples have been taken and are negative for <u>Listeria</u> spp. or <u>Listeria</u>-like organisms at that particular site. Swabs are analyzed for each day of production. If a sample finding is positive, testing of that site continues until nine consecutive samples are negative for <u>Listeria</u> spp. or <u>Listeria</u>-like organisms. Once nine consecutive samples are found negative, that site will returned to routine sampling.

Similarly, the food contact surface site that initially tests positive for <u>Listeria</u> spp. or <u>Listeria</u>-like organisms will be placed under intensified testing. If nine consecutive samples under the intensified testing are negative for <u>Listeria</u>, that site is returned to routine monitoring. However, if the food contact surface tests positive under the initial intensified sampling, sanitation for that area is designated as a CCP since <u>Listeria</u> cannot be considered a hazard not reasonably likely to occur. The site testing positive for <u>Listeria</u> would be considered a suspect harborage for <u>L. monocytogenes</u> and corrective actions taken. Testing becomes the verification step.

Intensified sampling under the CCP requires that 3 samples per day (one each at pre-op, 1<sup>st</sup> shift, 2<sup>nd</sup> shift) be taken until nine consecutive samples are negative for **both** <u>Listeria</u> spp. and <u>L. monocytogenes</u>. If a sample is positive for *Listeria* spp. but negative for <u>L. monocytogenes</u>, additional sampling days are added (3 samples per day) until nine consecutive samples are negative for both <u>Listeria</u> spp. and <u>L. monocytogenes</u>. All product that has contact with that particular site must be placed on hold pending testing results.

If nine consecutive samples are negative for <u>Listeria</u> spp. and <u>L. monocytogenes</u>, the site can be returned to routine sampling. Product can be released when the line and production date receive negative test results for <u>L. monocytogenes</u>. Any sites testing positive for <u>L. monocytogenes</u> would require testing of the product.

# Sentinel Site Program Example Flowchart

- 1. Routine Environmental Sampling
  - a. 5 samples/line/week
    - i. 3 food contact surface samples
    - ii. 2 non-food contact surface samples
    - iii. Listeria spp.
- 2. Non-food Contact Surface Testing
  - a. If negative for Listeria spp., continue Routine Environmental Testing
  - b. If positive for Listeria spp., intensify sampling
    - i. Collect 3 samples/site/day for 3 consecutive days for <u>Listeria</u> spp. (9 consecutive samples)
    - ii. If 9 consecutive samples are negative for <u>Listeria</u> spp., return to Routine Environmental Sampling
    - iii. If any sample is positive, continue sampling 3 samples/site/day until 9 consecutive samples are negative
- 3. Food Contact Surface (FCS) Testing
  - a. If negative for <u>Listeria</u> spp., continue Routine Environmental Testing.
  - b. If positive for Listeria spp., intensify sampling.
    - i. Collect 3 samples/site/day for 3 consecutive days for <u>Listeria</u> spp. (9 consecutive samples).
    - ii. If 9 consecutive samples are negative for <u>Listeria</u> spp., return to Routine Environmental Sampling.
    - iii. If any sample is positive, make sanitation for that site a CCP

### 4. CCP Testing

- a. Collect 3 samples samples/site/day for 3 consecutive days for <u>Listeria</u> spp. and <u>L. monocytogenes</u> (9 consecutive samples).
- b. If 9 consecutive samples are negative for <u>Listeria</u> spp. and <u>L. monocytogenes</u>, return to Routine Environmental Sampling and eliminate the CCP.
- c. If a sample is positive for <u>Listeria</u> spp. but negative for <u>L. monocytogenes</u>
  - i. Place product on hold
  - ii. Release product if site and production date have negative results for <u>L.</u> monocytogenes
  - iii. Continue testing until 9 consecutive samples are negative for <u>Listeria</u> spp. and <u>L. monocytogenes</u>, then return to Routine Environmental Sampling and eliminate the CCP
- d. If any sample is positive for <u>L. monocytogenes</u>, test the product for <u>L. monocytogenes</u>
  - <u>i.</u> Reprocess or destroy product testing positive for <u>L. monocytogenes</u>

#### E. References

#### A. Post-lethality Treatments and Antimicrobial Agents

- Bedie, B. K., J. Samelis, J.N. Sofos, K. E. Belk, J. A. Scanga, and G. C. Smith. 2001. Antimicrobials in the formulation to control <u>Listeria monocytogenes</u> postprocessing contamination on frankfurters stored at 4° C in vacuum packages. J. Food Protect. 64:1949-1955
- Gande, N., and Muriana, P. M. 2002. Pre-package surface pasteurization of ready-to-eat meats with radiant heat oven for reduction of <u>Listeria monocytogenes</u>. Accepted for publication, Journal of Food Protection.
- Glass, K. G., D. A. Granberg, A. L. Smith, A. M. McNamara, M. Hardin, J. Mattias, K. Ladwig, and E. A. Johnson. 2002. Inhibition of <u>Listeria monocytogenes</u> by sodium diacetate and sodium lactate on wieners and cooked bratwurst. J. Food Protect. 65: 116-123.
- Janes, M. E., .S. N Kooshesh and M.G. Johnson. 2002. Control of <u>Listeria monocytogenes</u> on the surface of refrigerated, ready-to-eat chicken coated with edible zein films containing nisin and calcium propionate. J. Food Sci. 67(No. 7): 2754-2757.
- Muriana, P.M. and W. Quimby, C.A. Davidson, and J. Grooms. 2002. Postpackage pasteurization of ready-to-eat deli meats by submersion heating for reduction of <u>Listeria monocytogenes</u>. J. Food Protect.65:963-969.
- Murphy, R.Y., L. K. Duncan, K.H. Driscoll, B.L. Beard, M. E. Berrang and J.A. Marcy. 2003. Determination of thermal lethality of <u>Listeria monocytogenes</u> in fully cooked chicken breast fillets and strips during post cook in-package pasteurization J. Food Protect 66:578-583.
- Murphy, R.Y., L. K. Duncan, E. R. Johnson, M.D. Davis, R. E. Wolfe, and H. G. Brown. 2001. Thermal lethality of <u>Salmonella senftenberg</u> and <u>Listeria innocua</u> in fully coked and packaged chicken breast strips via steam pasteurization. J. Food Protect. 64:2083-2087.
- Murphy, R.Y., L. K. Duncan, K.H. Driscoll, and J.A. Marcy. 2003. Lethality of <u>Salmonella</u> and <u>Listeria innocua</u> in fully cooked chicken breast meat products during postcook in-package pasteurization. J. Food Protect. 66:242-248.
- Murphy, R.Y., L.K. Duncan, K.H. Driscoll, J.A. Marcy, and B.L. Beard. 2003. Thermal inactivation of <u>Listeria monocytogenes</u> on ready-to-eat turkey breast meat products during post-cook in-package pasteurization via hot water. J. Food Protect. (accepted).

Porto, A.C.S., B. D. G. M. Franco, E.S. Sant'anna, J. E. Call, A. Piva, and J. B. Luchansky. 2002. Viability of a five-strain mixture of <u>Listeria monocytogenes</u> in vacuum-sealed packages of frankfurters, commercially prepared with and without 2.0 or 3.0% added potassium lactate, during extended storage at 4 and 10° C. J. Food Prot. 65:308-315.

PURAC America, Inc. Opti.Form <u>Listeria</u> Control Model. 2003. Personal Communication

Raghubeer, E.V. and E.D. Ting. 2003. The Effects of high hydrostatic pressure (HPP) on <u>Listeria monocytogenes</u> in RTE meat products. Avure Technologies, Inc. Submitted for publication.

Samelis, J. G.K. Bedie, J.N. Sofos, K.E. Belk, J.A. Scanga, and G.C. Smith. 2002. Control of <u>Listeria monocytogenes</u> with combined antimicrobials after postprocess contamination and extended storage of frankfurters at 4° C in vacuum packages. J. Food Protect. 65: 299-307.

Seman, D.L., A. C. Borger, J. D. Meyer, P. A. Hall, and A.L. Milkowski. 2002. Modeling the growth of <u>Listeria monocytogenes</u> in cured, ready-to-eat processed meat products by manipulation of sodium chloride, sodium diacetate, potassium lactate, and product moisture control. J. Food Protect 65:651-658.

Viskase Corporation. NOJAX® AL. 2003. Personal Communication.

### **B.** Sanitation Guidelines

AMI. 1988. Interim guideline: microbial control during production of ready-to-eat meat products.

Anonymous. 2003. Sanitation systems and solutions. Food Safety 9(1):30-40, 45, 48-9.

Anonymous. 1999. Guidelines for developing good manufacturing practices (GMPs). standard operating procedures (SOPs), and environmental sampling/testing recommendations (ESTRs). Ready-to-Eat Products

Ednie, D. L, R. Wilson and M. Lang. 1998. Comparison of two sanitation monitoring methods in an animal research facility. Comtem. Top. Lab. Anim. Sci. 37(6):71-4.

Grau, F. H. Smallgoods and listeria. 1996. Food Australia. 48 (2): 81-83.

Huss, H. H., L. V. Jorgensen and B. F. Vogel. 2000. Control options for *Listeria monocytogenes* in seafoods. Int. J. Food Microbiol. 62:267-74.

Joint Task Force on Control of Microbial Pathogens. 1999. Interim guidelines: microbial control during production of ready-to-eat meat and poultry products.

Kohn, B. A., K. Costello and A. B. Philips. 1997. HACCP verification procedures made easier by quantitative <u>Listeria</u> testing. Dairy Food Environ. Sanit. 17(2):76-80.

Krysinski, E. P., L. J. Brown, and T. J. Marchisello.1992. Effect of cleaners and sanitizers on <u>Listeria monocytogenes</u> attached to product contact surfaces. J. Food Protect. 55:(4):246-251.

Moore, G. and C. Griffith. 2002. A comparison of surface sampling methods for detecting coliforms on food contact surfaces. Food Microbiol. 19:65-73.

National Advisory Committee on the Microbiological Criteria for Foods. 1991. Int. J. Food Microbiol. 14(3/4):232-37.

Seeger, K. and M. W. Griffiths. 1994. Adenosine triphosphate bioluminescence for hygiene monitoring in health care institutions. J. Food Prot. 57(6);509-12.

Silliker Laboratories. 1996. Smart sanitation: priniciples and practices for effectively cleaning your plant. Video.

Suslow, T. and L. Harris. Guidelines for Controlling <u>Listeria monocytogenes</u> in Smallto Medium-Scale Packing and Fresh Cut Operations. 2000. University of California Publication 8015.

Tompkin, R. B., V. N. Scott, D. T. Bernard, W. H. Sveum, and K. S. Gombas. 1999. Guidelines to Prevent Post Processing Contamination from <u>Listeria monocytogenes</u>. Dairy, Food and Environmental Sanitation. 19 (8): 551-562.

Tompkin, R. B. 2002. Control of <u>Listeria monocytogenes</u> in the Food-Processing Environment. J. Food Prot. 65(4):709-25.



#### IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

ficant(s): HOWARD

Serial No.: 09/777,472

Filed: 2/6/2001

Title: PASTEURIZATION OF FOOD

**PRODUCTS** 

Attorney Docket No.: UNITHERM-2 (00-

Group Art Unit: 1761

Examiner:

TO 1700 George Chan Pui Yeung

Commissioner for Patents P. O. Box 1450 Alexandria, VA 22313-1450

### SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Dear Sir:

Th	is S	Suppl	lemental	Information	Disc	losure	Sta	tement	15	submi	tted:
----	------	-------	----------	-------------	------	--------	-----	--------	----	-------	-------

- under 37 CFR 1.97(b), or (Within three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)
- X under 37 CFR 1.97(c) together with either a:
  - Statement under 37 CFR 1.97(e), or
  - X a \$180.00 fee under 37 CFR 1.17(p), or (After the CFR 1.97(b) time period, but before final action or notice of allowance, whichever occurs first)
- under 37 CFR 1.97(d) together with a:
  - \_\_\_ Statement under 37 CFR 1.97(e), and
  - \_ a \$180.00 fee set forth in 37 CFR 1.17(p). (Filed after final action or notice of allowance, whichever occurs first, but
    - before payment of the issue fee)
- Applicant(s) submit herewith Form PTO 1449-Information Disclosure Citation together with copies, of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56.

12/24/2003 EFLORES 00000073 09777472

01 FC:1806

180.00 QP

Applicant submits that the above references taken alone or in combination neither anticipate nor render obvious the present invention. Consideration of the foregoing in relation to this application is respectfully requested.

It is requested that the information disclosed herein be made of record in this application.

Respectfully submitted,

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, P. O. Box 1450, Alexandria, VA 22313-1450

Date of Deposit: December 2, 200

Typed Name: Carol Welch

DENNIS D. BROWN

Attorney/Agent for Applicant(s)

Reg. No. 33559

Date:  $\frac{2}{17}$ 

Telephone No.: 918/599-0621

214688.1

PTO/SB/08A (06-03)

Approved for use through 07/31/2003. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE are required to respond to a collection of information unless it displays a valid OMB control number.

Complete if Known

Under the Paperwork Reduct Substitute for form 1449A/PTO

1

Sheet

# INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(use as many sheets as necessary )

Application Number	09/777,472
Filing Date	2/6/2001
First Named Inventor	HOWARD
Art Unit	1761
Examiner Name	George Yeung
Attorney Docket Number	UNITHERM-2 (00-627)

	U.S. PATENT DOCUMENTS						
Examiner	Cite	Cite Document Number	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant		
Initials*	No.1	Number-Kind Code 2 (# known)		, ppinosin or orion potential	Figures Appear		
	AA	US-2,779,681	01/29/1957	SELL, ET AL.			
	вв	US-2,364,049	12/05/1944	D. BENSEL			
	CC	US-3,597,228	8/3/1971	JEPPSON, ET AL.			
	DD	US-3,906,115	09/16/1975	JEPPSON			
	EE	US-3,961,090	06/01/1976	WEINER, ET AL.			
	FF	US-3,966,980	06/29/1976	MCGUCKIAN			
	GG	US-4,391,862	07/05/1983	BORNSTEIN, ET AL.			
	НН	US-4,448,792	05/15/1984	SCHIRMER			
	II	US-H762	04/03/1990	DEMASI, ET AL.			
	JJ	US-4,948,610	08/14/1990	GOGLIO			
	кк	US-5,269,216	12/14/1993	COROMINAS			
	LL	US-5,298,270	03/29/1994	MORGAN			
	мм	US-5,356,649	10/18/1994	LAMOTTA, ET AL.			
	NN	US-5,366,746	11/22/1994	MENDENHALL			
	00	US-5,466,498	11/14/1995	FORLONI, ET AL.			
	PP	US-5,470,597	11/28/1995	MENDENHALL			
	QQ	US-5,374,437	12/20/1994	COROMINAS			
	RR	US-5,512,312	04/30/1996	FORNEY, ET AL.			
	SS	US-5,741,536	04/21/1998	MAUER, ET AL.			
	TT	US-5.952.027	09/14/1999	SINGH			

3

	FOREIGN PATENT DOCUMENTS								
Examiner Initials*	Cite No.1	Foreign Patent Document Country Code³ -Number⁴- Kind Code⁵ (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	T			
						╀			
						_			
						-			

Examiner Signature	Date Considered

\*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant. Applicant's unique citation designation number (optional). See Kinds Codes of US PTO Patent Documents at www.upsto.gov or MPEP 901.04. <sup>3</sup> Enter Office that issued the document, by the two-letter code (WIPO Standard ST.3). patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. <sup>5</sup> Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST. 16 if possible. <sup>6</sup> Applicant is to place a check mark here if English language Translation is attached.

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

PTO/SB/08B (06-03)

Approved for use through 06/30/2003. OMB 0651-0031 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCION U.S. Patent U.S. DEPARTMENT U.S. Patent U.S. DEPARTMENT U.S. Patent U.S. DEPARTMENT U.S. Patent U.S. DEPARTMENT U.S. DEPARTMEN

Substitute for form 1449B/PTO Complete if Known Application Number 09/777,472 INFORMATION DISCLOSURE Filing Date 2/6/2001 First Named Inventor STATEMENT BY APPLICANT **HOWARD** Art Unit 1761 **Examiner Name** (use as many sheets as necessary ) George Yeung Attorney Docket Number UNITHERM-2 (00-627) Sheet

		NON PATENT LITERATURE DOCUMENTS				
Examiner Initials*	TOTE I magazine infinal serial symposium catalog etc.) date pagets), yolunte-issue fluttibetts), bublistiet,					
	υυ	Description of the Unitherm browning system				
	vv	Summary Judgment Order by U.S. District Court for the Western District of Oklahoma, Case No. CIV-01-347-C; Unitherm Food Systems, Inc. et al. v. Swift-Eckrich, Inc., d/b/a ConAgra Refrigerated Foods.				
	ww	Smoking & Browning Under 10 minutes - Unitherm advertisement				
:	xx	Unitherm Bulletin - "Browning in Traditional Continuous Ovens"				
	YY	"Application of Infra-red Radiation in Food Processing," PROFESSOR A.S. GINZBURG, Chemical and Process Engineering Series, 1969	_			
	ZZ	"Infra-Red Radiation for Food Processing II. Calculation of Heat Penetration During Infra-Red Frying of Meat Products," MAGNUS DAGERSKOG, , LebensmWiss u. Technol., 12, 252-257 (1979)				
	AAA	Heat Transfer and Food Products"; BENGT HALLSTRON, ET AL., pgs. 214-231, Elsevier Applied Science Publishers Ltd. 1988				
	ввв	"Pasteurizing Protection," The National Provisioner, April 1, 1999				
	ссс	Studies on the Application of Infrared in Food Processing, ASSELBERGS, ET AL. presented at the 20th annual meeting, Institute of Food Technologists, May 17, 1960				
	DDD	"COOKING METHODS FOR ELIMINATION OF Salmonella typhimurium EXPERIMENTSL SURFACE CONTAMINANT FROM RARE DRY-ROASTED BEEF ROASTS," L.C. BLANKENSHIP, ET AL., <u>Journal of Food Science</u> , Vol. 45, (1980)				
	EEE	"Infrared Radiative Drying in Food Engineering: A Process Analysis," CONSTANTINE SANDU, <u>Biotechnology</u> <u>Progress</u> , (Vol. 2, No. 3) Sept. 1986				

Examiner	Date	
Signature	Considered	

<sup>\*</sup>EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

considered. Include copy of this form with next communication to applicant.

Applicant's unique citation designation number (optional). Applicant is to place a check mark here if English language Translation is attached. This collection of information is required by 37 CFR 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 2 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

PTC/SB/08B (06-03)

Approved for use through 06/30/2003. OMB 0651-0031

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE ons are required to respond to a collection of information unless it displays a valid OMB control number Under the Paperwork Reduction A TARE THAT

Substitute for form 1449B/PTO				C	mplete if Known
				Application Number	09/777,472
INFORMATION DISCLOSURE				Filing Date	2/6/2001
	ATEMENT BY A			First Named Inventor	HOWARD
		PPL	ICANI	Art Unit	1761
use as many sheets as necessary)				Examiner Name	George Yeung
Sheet	3	of	3	Attorney Docket Number	UNITHERM-2 (00-627)

		NON PATENT LITERATURE DOCUMENTS	
Examiner Initials*	Cite No.1	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T²
	FFF	"The A.G.S. Food System Chilled Pasteurized Food", COL. MCGUCKIAN, May 1969	
	GGG	"The microbiological shelf life of vacuum packed broiled chickens," MULDER, ET AL., Speiderholt Institute for poultry research, the Netherlands, May, 1974	
	ННН	"Microbiological Stability of Pasteurized Ham Subjected to a Secondary Treatment in Retort Pouches, DELAQUIS, ET AL., <u>Journal of Food Protection</u> , Vol. 49, No. 1, pgs. 42-46, Jan. 1986	
	Ш	"Food preservation by combined methods," L. LEISTER, Food Research International 25, 1992, pgs. 151-158	
	JJJ	"Effects of Blade Tenderization, Vacuum Massage Time and Salt Level on Chemical, Textural and Sensory Characteristics of Precooked Chuck Roasts," S. D. SCHACKELFORD, ET Al., <u>Journal of Food Science</u> , Vol. 54, No. 4, 1989	
	ккк	"Reduction of Listeria monocytogenes in Precooked Vacuum-Packaged Beef Using Postpackaging Pasteurization," D. KAY COOKSEY, ET AL., <u>Journal of Food Protection</u> , Vol. 56, December 1993, pgs. 1034-1038	
	LLL	"Survival of Listeria monocytogenes in Postpasteurized Precooked Beef Roasts," MARGARET D. HARDIN, ET AL., Journal of Food Protection, Vol. 56, No. 8, pages 655-660 (August 1993)	
	ммм	"Food Preservation by Hurdle-Technology," L. LEISTER, ET AL., pgs. 511-520, Proceedings of the 1993 Food Preservation 2000 Conference, 19-21 October 1993, Natick, Massachusetts	-I —
	000	"Food preservation by hurdle technology," LOTHAR LEISTER, ET AL., <u>Trends in Food Science &amp; Technology</u> , February 1995 (Vol. 6), pgs. 41-46	
	PPP	"Extending the Shelf-Life of Chilled Ready Meals," ROBERT SHAW, Meat Quality and Meat Packaging, June 23, 1998	
	QQQ	"New Methods of Food Preservation," edited by G. W. GOULD, published 1995, Chapman & Hall	
	RRR	"Reducing Process Variation in the Cooking and Smoking Process," ROBERT E. HANSON, 50th Annual Reciprocal Meat Conference, Vol. 50, 1997.	
	SSS	"Radiant Wall Oven Applications," © 1996, Pyramid Manufacturing.	
	TTT	"Shelf Life Extension and Pathogen Reduction of Fresh Chicken Through Surface Pasteurization Using Radian Heat and Anti-Microbial Agents," MD. MAHBUBUL ISLAM, for B. Astrakhan Technical Institute for Fisheries, USSR, 1981, Dissertation to the Graduate Faculty of the University of Georgia, Athens Georgia 1998	
	UUU	"Extended Shelf Life Refrigerated Foods: Microbiological Quality and Safety,"ELMER H. MARTH, <u>Food</u> <u>Technology</u> , Vol. 52, No. 2, February 1998.	
	vvv	"Post Processing Pasteurization of Processed Meats," E. JEFFERY RHODEHAMEL, ET AL., 2nd Annual Reciprocal Meat Conference, June 20-23, O.S.U., Stillwater, OK	
	ww w	"Basic aspects of food preservation by hurdle technology," LOTHAR LEISTNER, International Journal of Food Microbiology, 55 (2000)	

#### United States Statutory Invention Registration

[11] Reg. Number:

H762

DeMasi et al.

[43] Published:

Apr. 3, 1990

[54]	POST-PA	STEURIZA	TION
------	---------	----------	------

[75] Inventors: 'Thomas W. DeMasi; Karl R. Deily, both of Greenville, S.C.

[73] Assignee: W. R. Grace & Co.-Conn., Duncan, S.C.

[21] Appl. No.: 334,834

[22] Filed: Apr. 7, 1989

426/129; 426/394; 426/412

Primary Examiner—Matthew A. Thexton
Assistant Examiner—Joseph D. Anthony
Attorney, Agent, or Firm—John J. Toney; William D.
Lee, Jr.; Mark B. Quatt

[57] ABSTRACT

Precooked food products, especially meat products,

which have been unpackaged and further processed, are repackaged in a heat tolerant structure and exposed to temperatures of between about 160° F. and 205° F. for 30 seconds to 10 minutes, time and temperature depending on the particular product. This post pasteurization treatment extends the shelf life of the product.

#### 4 Claims, No Drawings

A statutory invention registration is not a patent. It has the defensive attributes of a patent but does not have the enforceable attributes of a patent. No article or advertisement or the like may use the term patent, or any term suggestive of a patent, when referring to a statutory invention registration. For more specific information on the rights associated with a statutory invention registration see 35 U.S.C. 157.

#### POST-PASTEURIZATION

#### BACKGROUND OF THE INVENTION

The present invention relates t the processing of food products and more particularly t the further processing of cooked meat products.

The processed meat industry is a large and growing

portion of the total food packaging market.

"Processed meats" includes luncheon meats, smoked 10 meat products, reconstituted and other forms of meat which are often packaged and sometimes repackaged, and also often cooked before shipping to a point of sale.

Cooking containers, typically thermoplastic bags 15 such as the CN bags available from W. R. Grace & Co.-Conn. through its Cryovac Division, are often used

in packaging and cooking processed meats.

A typical practice in the processed meats industry is to strip the cook-in bag from the processed meat after 20 cooking, followed by some form of further processing. This further processing can include the addition of colorants and seasonings, slicing of the processed meat product to smaller portions, glazing and the like.

While these further processing procedures are often 25 done to enhance the value and marketability of the processed meat products, they can also result in undesirable recontamination of the product surface with microrganisms which the cooking process would have

typically destroyed.

The inventor has found that by taking such reprocessed cooked meats or other types of processed meat items, and placing them in a heat tolerant container such as a cooking bag, and exposing the repackaged product. to a heat treatment of the product surface, a reduction in 35 the bacterial load which was reintroduced to the product surface is obtained.

Reprocessing can involve submerging the resurfaced product in hot water (160° F. to 205° F.), or a comparable medium for dwell times ranging from 30 seconds to 40 10 minutes.

#### SUMMARY OF THE INVENTION

In one aspect of the invention, a method of treating cooked meat products comprises packaging the cooked 45 meat product in a flexible heat tolerant container; placing the packaged meat product in a heated medium kept at a temperature between about 160° F. and 205° F.; and maintaining the package in the heated medium for between about 30 seconds and 10 minutes.

In another aspect of the invention, the invention comprises a packaged meat product which has been cooked in a bag or casing; removed from the bag or casing; further processed; repackaged in a heat tolerant container; exposed to a temperature of between about 160° 55 ity. F. and 205° F. for a period of between about 30 seconds and 10 minutes; and cooled.

#### DESCRIPTION OF THE PREFERRED **EMBODIMENTS**

The present invention provides a means for reducing the microbial numbers which are introduced during re-processing of cooked unpackaged processed meat

The microbes referred to here are generally those 65 that can affect the shelf life and organoleptic quality of the food product. These include lactic acid organisms, aerobes and anaerobes.

It is well known that as microbial counts climb to 100,000 to 1,000,000 count/gram, the food product

becomes increasingly unacceptable.

Although shelf life is a somewhat subjective barometer of food quality, organoleptic and ther measures can be used t determine shelf life f r a given food product.

The inventor has found that for example for roast beef, the shelf life using the post pasteurization process of the present invention is extended from 45 days (without reheating) to 60 to 90 days (with reheating).

For turkey breasts, shelf life using the post pasteurization process is extended from 21 to 31 days without the use of this process to between 60 and 90 days with the

use of this process.

The invention has also been found useful in the treatment of ham. The presence of salt and nitrites in ham will also assist in shelf life, so that improvements attained by the use of the post pasteurization process of the present invention are less dramatic.

The optimum temperature range and dwell time for reheating cooked and repackaged food products is product dependent and also time/temperature related.

As an example, some high fat products such as sausage can only withstand a limited reheating before purge and discoloration.

In the case of ham and turkey breast products, it has been found that a temperature of between about 180° F. and 200° F., and more preferably about 190° F., held for between 60 and 90 seconds is optimal in reducing microbe count and extending shelf life.

Within any temperature range and dwell time range, generally the higher the temperature the lower the required dwell time to obtain optimum results.

While the exact effect on the bacteria or microbes from this post pasteurization treatment is not completely understood, it is suspected that the bacteria are either destroyed or injured so as to "inactivate" the bacteria and prevent product spoilage.

In a typical food processing operation, a meat product such as furkey breast or roast beef will be co à cook in bag such as a Cryovac CN 530 cook in bag After the cooking cycle is completed, the cooked food

product is removed from the bag.

At this point, further processing such as the addition of colorants and seasonings, slicing or trimming of the food product, the addition of glazing (caramel) and similar processing is sometimes done. It is during this reprocessing that microorganisms typically destroyed or inactivated in the original cooking process can be reintroduced to the food surface. In the case of meat products, the growth of the microbe population can be especially rapid pending upon the exposure to personnel, equipment, and atmosphere in the processing facil-

The present invention provides an effective way of delaying the microbial growth created by such reprocessing. The reprocessed food product such as a meat product is packaged in a heat tolerant container or 60 structure such as the CN 530 material used for the original heating process. Other heat tolerant materials, bags, pouches and structures may also be used depending on the time/temperature requirement and the degree of heat tolerance of the container, as well as other factors such as cost f the heat tolerant material.

The prepackaged food product is then exposed to a regime of high temperatures for a shirt period of time. It has been found that overall the optimal temperature

The heating medium is preferably hot water, although steam (for example in a smoke house) or other h t liquids, or heated gasses such as heated air may also 5 be used in some cases. In most applicati ns and for most food products, hot water is the preferred heating medium.

The invention may be further understood by reference to the examples given below. The TBA values 1 referred to in the examples refer to rancidity (fat breakdown). A standard test is used for determining TBA values, which measures the presence of breakdown products.

#### EXAMPLE 1

Twenty-four previously nonvacuumized whole hams were obtained approximately three days after production. Employing unsanitary practices (no gloves, etc.), the hams were removed from their stockinettes, halved 20 and placed in either a B 540 (9"×20") barrier bag or a CN 530 (9" or 10") bag. Both of these bag products are available from W. R. Grace & Co.-Conn. through its Cryovac Division. All products were vacuumized and heat-sealed on a Koch/Multivac AG-800 machine. Nine half hams packaged in B 540 and nine packaged in CN 530 were shrunk for two seconds in a Groen Model 500 Water Cook Tank operating at 205° F. Samples treated in this manner served as experimental controls. The remainder of the CN 530-packaged hams (27) were exposed to 205° F. for either 30, 60 or 90 seconds in a Groen Model 500 to pasteurize the surface of the product. A three-minute period was allowed between each pasteurization treatment to ensure equilibrium of the cook tank temperature. All samples were chilled in an ice water bath immediately following pasteurization and were placed in an open display cabinet operating at 34° F. to 38° F. and 80 to 120 ft-c. Samples were evaluated after Day 1 and 6 weeks, 12 weeks and 18 weeks of

Replicate ham samples were analyzed in duplicate or triplicate for the total aerobic (20° C.), total anaeorbic (20° C.), lactobacilli and pseudomonas counts after each storage period. During the first evaluation period, "swab" and "scalpel" sampling methods were employed. Both sampling techniques produced similar results so the "scalpel" method was used for all subsequent evaluation periods.

In addition to microbial analyses, pH and TBA values were determined on 18-week-old samples. Ham color and purge accumulation and viscosity were subjectively determined throughout the test.

- The results are graphically summarized in Tables 1

TABLE 1

Average Microbial Population on the Surface of
Vacuum-Packaged Half Hams Exposed to 205° F.
for 2, 30, 60 or 90 Seconds

			Organisms/gm*			
Organism	Treatment <sup>d</sup>	Day 1	6 Weeks	12 Weeks	18 Weeks	
Total Aerobes	Barrier Bag	- 2.18°	6.010	6.770	6.48°	
	( 2 Sec.) CN 530 ( 2 Sec.)	2.10	6.040	6.840	6.65°	
	(30 Sec.)	2.00	6.46b	6.700	6.40°	
	(60 Sec.)	2.00°	2.055	4.30b	4.840	

TABLE 1-continued

Average Microbial Population on the Surface of Vacuum-Packaged Half Hams Exposed to 205° F.

	for 2, 30, 60	or 90 Se	conds		
· -	· · ·		Organisms/gm <sup>e</sup>		
Organism	Treatment	Day	6 Weeks	12 Weeks	18 Weeks
	(90 Sec.)	2.00°	2.05°	2.15°	2.22
Total	<b>(30 000)</b>				
Anserobes	Barrier Bag				
•	( 2 Sec.) CN 530	2.00°	6.00°	6.37°	5.66°
•	( 2 Sec.)	2.100	6.00°	6.540	5.840
	(30 Sec.)	2.000	5.066	5.784	5.964
•	(60 Sec.)	2.00°	2.44°	3.906	4.296
Lactobacillus	(90 Sec.) Barrier Bag	2.00°	2.53°	2.50°	2.50°
Organisms	( 2 Sec.) CN530	2.000	6.80°	6.78	6.50°
	( 2 Sec.)	2.440	6.950	6.769	6.70°
	(30 Sec.)	2.004	4.86	5.59	6.640
	(60 Sec.)	2.00	2.18°	4.18	4.656
•	(90 Sec.)	2.180	2.00°	2.30°	2.22°

abcFor each type of organism evaluated, any two means within a colo same or one of the same letters are not significantly (P < 0.05) different (analysis ucted according to SAS General Linear Models Procedures). Treatment = Packaging material and length of expo Mean Log of total counts on the surface of half ham

TABLE 2

I DA and	H Values of Half Har	113 HOW THEEK	
Packaging Material	Exposure Time at 205° F.	Mean pH Value	Mean TBA Value*
Barrier Bag	2 Sec.	5.25	0.37
CN530	2 Sec.	5.38	0.24
CN530	30 Sec.	5.18	0.34
CN530	60 Sec.	6.02	0.40
CN530	90 Sec.	6.02	0.36

"TBA values greater than 1.0 indicate rancidity.

During the test, the total aerobic population, the total anaerobic population and the lactobacilli organisms 40 showed compatible responses due to pasteurization and storage. Pseudomonas organisms remained constant (<100) throughout the test, regardless of the treatment or the sampling period. Although there were no differences in the microbial population at Day 1, the microbial numbers of hams which were pasteurized for 60 or 90 seconds remained lower than other samples throughout the remainder of the test.

Table 1 indicates that hams which were pasteurized for 60 or 90 seconds had a microbial population which was significantly less than those found in Barrier Bag or CN 530 controls at each week of storage. Hams which were pasteurized for 30 seconds had counts which were significantly less than controls up to the 12th week of storage, but this difference in microbial numbers diminished by the 18th week of storage. From the results seen in Table 1, it appears that the 60- and 90-second pasteurization treatments, and to a lesser extent the 30-second treatment, significantly affected the outgrowth of all microbial inhabitants during storage. No differences could be seen in rancidity development (indicated by TBA values over 1.0), but hams which received a 60or 90-second pasteurization had pH values at Week 18 which were 0.64 to 0.84 pH units above the rest. Lower pH values (at 2 seconds and 30 seconds) are indicative 65 of increased growth flactic acid producing bacteria.

In addition to these results, visual evaluations were made. A visible, clear purge began to accumulate and increase in quantity after the first week of storage. CN 530 samples pasteurized for 30 seconds and Barrier Bag and CN 530 controls had a milky white purge after 12 weeks of storage. Hams pasteurized for 60 or 90 seconds had a clear purge accumulation which increased during the test. These latter two samples were judged to be acceptable though, as many processors only feel there is a loss in quality (shelf life) when a milky purge accumulates

#### **EXAMPLE 2**

A precooked turkey product and a smoked sausage product were removed from the original packaging material and dipped into an inoculum suspension.

For purposes of this example, several inocula were prepared. These consisted of several species each of 15 streptococcus faecium, salmonella spp. and Clostridium Sporogenes. Both mixed species and single species inocula were used.

The inoculated products were placed on a stainless steel rack and allowed to drain for at least two minutes to remove excess liquid. The inoculated product was then placed into Cryovac CN 530 bags and sealed using a Koch/Multivac A 300 packaging machine.

Immersion heating was accomplished using a water tank heated by steam injection with agitation to approximately 190° F. Immersion time was about 60 seconds. The product was then cooled immediately for about 60 seconds.

A mixed species inoculum was prepared by combining equal volumes of the single species inocula.

The results of immersing the inoculated products in the steam bath are itemized in Tables 3 through 5.

#### TABLE 3

Counts of C. sporogenes for uninoculated turkey-breast and sausage, and turkey breast and sausage inoculated with C. sporogenes at the 106 and 108 spores/ml level in single (S) and mixed (M) species inocula.

(S) and inixed (M) species most						
SAMPLE DESCRIP- TION	IN- OCULUM TYPE	IN- OCULUM LEVEL	MEAN (CFU/IN²) (turkey breast)	MEAN (CFU/IN <sup>2</sup> ) (Sausage)		
uninoculated	_	_	<1.0 × 10°	1.0 10*		
inoculum unheated	S S	10 <sup>6</sup> 10 <sup>6</sup>	$4.0 \times 10^4$ $1.2 \times 10^3$	$4.0 \times 10^4$ $2.1 \times 10^2$	و	
heated -	S ·	10 <sup>6</sup>	$7.8 \times 10^{2}$ $5.3 \times 10^{6}$	$2.0 \times 10^{2}$ $5.3 \times 10^{6}$	•	
inoculum unheated	M	10 <sup>6</sup>	1.3 × 10 <sup>3</sup> 7.5 × 10 <sup>2</sup>	$7.3 \times 10^{2}$ $4.5 \times 10^{2}$		
heated inoculum	M S	10 <sup>2</sup>	1.0 × 10 <sup>7</sup> 6.6 × 10 <sup>4</sup>	1.0 × 10 4.2 × 10 <sup>4</sup>		
unheated heated	\$ \$	10 <sup>8</sup> 10 <sup>8</sup>	$6.6 \times 10^4$	$2.1 \times 10^4$	. :	
inoculum unheated	M M	10 <sup>8</sup> 10 <sup>8</sup>	4.0 × 10 <sup>8</sup> 1.4 × 10 <sup>5</sup>	4.0 × 10 <sup>8</sup> 6.7 × 10 <sup>4</sup>		
heated	M	108	$8.2 \times 10^4$	$4.7 \times 10^4$		

#### TABLE 4

Counts of Salmonellae for turkey breast and sausage inoculated with Salmonella at the 10<sup>7</sup> and 10<sup>9</sup> per ml level in single and mixed species inocula.

SAMPLE DESCRIP- TION	INOCULUM TYPE <sup>I</sup>	IN- OCULUM LEVEL	MEAN (CFU/IN <sup>2</sup> ) (turkey breast)	MEAN (CFU/IN <sup>2</sup> ) (Sausage)
inoculum	S	107	$8.5 \times 10^{6}$	$8.5 \times 10^6$
unheated	Š ·	107	$2.5 \times 10^5$	$1.4 \times 10^{5}$
heated	Š	107	$9.8 \times 10^{3}$	$8.7 \times 10^{3}$
inoculum	M	107	$1.4 \times 10^{8}$	$1.4 \times 10^{8}$
unheated	M	107	$8.8 \times 10^4$	$5.7 \times 10^4$
heated	M	107	$1.8 \times 10^{3}$	$5.6 \times 10^{3}$
inoculum	Š	109	$2.6 \times 10^8$	$2.6 \times 10^{8}$
unheated	Š	109	$1.4 \times 10^{7}$	$5.0 \times 10^6$

#### **TABLE 4-continued**

Counts of Salmonellae for turkey breast and sausage inoculated with Salmonella at the 10<sup>7</sup> and 10<sup>9</sup> per mi level in single and mixed species inocula.

SAMPLE DESCRIP- TION	INOCULUM TYPE <sup>1</sup>	IN- OCULUM LEVEL	MEAN (CFU/IN²) (turkey bresst)	MEAN (CFU/IN <sup>2</sup> ) (Sausage)
heated inoculum unheated heated	S M M M	10 <sup>9</sup> 10 <sup>9</sup> 10 <sup>9</sup>	$3.8 \times 10^{5}$ $1.4 \times 10^{10}$ $2.3 \times 10^{7}$ $3.6 \times 10^{5}$	1.3 × 10 <sup>6</sup> 1.4 × 10 <sup>10</sup> 3.5 × 10 <sup>6</sup> 4.8 × 10 <sup>5</sup>

#### TABLE 5

Counts of S. faccium for turkey breast and sausage inoculated with S. faccium at the 10<sup>3</sup> and 10<sup>9</sup> per mi level in single and mixed species inocula.

0	SAMPLE DESCRIP- TION	INOCULUM TYPE <sup>1</sup>	IN- OCULUM LEVEL	MEAN (CFU/IN <sup>2</sup> (turkey breast)	MEAN (CFU/IN <sup>2</sup> (Sausage
:5	inoculum	s ·	107	$3.6 \times 10^{6}$	$3.6 \times 10^{6}$
	unheated	S	t0 <sup>7</sup>	$9.9 \times 10^4$	7.2 × 10 <sup>4</sup>
	heated	·S	10 <sup>7</sup>	$8.7 \times 10^3$	$9.8 \times 10^{3}$
	inoculum	M	10 <sup>7</sup>	$3.2 \times 10^8$	$3.2 \times 10^8$
	unheated	M	107	$9.9 \times 10^4$	$9.8 \times 10^4$
	heated	· M	107	$8.7 \times 10^{3}$	$8.6 \times 10^{3}$
	inoculum	S	109	$4.6 \times 10^6$	$4.6 \times 10^{9}$
	unheated		109	8.0 × 10 <sup>6</sup>	$4.7 \times 10^6$
	heated	S S	109	$7.0 \times 10^{5}$	$8.9 \times 10^{5}$
	inoculum	. й	109	4.2 × 10 <sup>10</sup>	$4.2 \times 10^{10}$
	unheated	M	109	$2.7 \times 10^{7}$	5.0 × 106
	heated	M	109	$6.8 \times 10^5$	$1.1 \times 10^{6}$

The mean values are an average of between 1 and 3 replicate measurements, each replicate measure having two duplicates.

The results found in Tables 3 through 5 represent a "worse case" scenario and are somewhat artificial in that artificially high levels of microbial organisms were introduced to the surface of the test products. Even here, improvements were obtained.

#### **EXAMPLE 3**

A second study along the same lines as that of Example 2 was performed, using the same two products and
three organisms found in Tables 3 through 5. In this
study, pasteurization was performed at 205° F. for 2
minutes.

The results were substantially like those obtained by the treatment of Example 2.

#### **EXAMPLE 4**

Caramel-glazed cooked turkey breasts were exposed to a temperature of 195° F. in a shrink tunnel for 1 second, and then to the same temperature for a period of 90 seconds. It was found that the shelf life of the food product was extended from about 14 to 21 days of shelf life (without treatment) to about 60 days with the heat treatment just described.

#### EXAMPLE 5

Whole top rounds of whole muscle roast beef were injected 10% with a solution of salt and phosphates. They were packaged in a cook-and-strip material, CN 500, and were cooked to an internal temperature f 145° F. Following chilling, the beef was rubbed with a caramel-based seasoning, halved and packaged in CN 530.

7

Post-pasteurization was conducted at 205° F. for 5 minutes. Roast beef is an uncured item with lower salt levels which can withstand longer dwell times without any detrimental effect to product quality.

The results were about the same as f r Example 1.

These in-house results are in agreement with actual production experience in the field. A 10-minute dwell time at 170° F. or a 5-minute exposure to 190° F. gave counts on split insides which were lower after 56 days than non-pasteurized controls after 28 days. In essence, 10 the shelf life was doubled.

While the invention may be understood with respect t the examples describing specific embodiments of the invention, those skilled in the art will understand that appropriate modifications in both length of time and 15 temperature range for pasteurization, depending on the particular product to be pasteurized, will become apparent to one skilled in the art after reviewing the specification.

What is claimed is:

1. A method of treating cooked meat products comprising:

(a) packaging the cooked meat product in a flexible heat-tolerant container;

(b) placing the packaged meat product in a heated medium kept at a temperature f between about 160° F. and 205° F.; and

(c) maintaining the package in the heated medium for between about 30 seconds and 10 minutes.

2. The method of claim 1 wherein the packaged meat product is immersed into hot water.

3. The method of claim 1 wherein the immersed meat product is kept at a temperature of between about 180° F. and 200° F. for a period of between about 30 and 90 seconds.

4. A packaged meat product which has been:

(a) cooked in a bag or casing;

(b) removed from the bag or casing;

(c) further processed;

(d) repackaged in a heat tolerant container;

(e) exposed to a temperature of between about 160° F. and 205° F. for a period of between about 30 seconds and 10 minutes; and cooled.

25

20

30

35

.

50

60

65

#### The Unitherm Browning Process

The inventor in this application, David Howard, is the President of Unitherm Food Systems, Inc. David Howard and Unitherm developed and sell a browning process which has been found by the United States District Court for the Western District of Oklahoma to fully anticipate and invalidate all of the claims of U.S. Patent No. 5,952,027, issued to Singh. A copy of the Court's order declaring the Singh patent invalid is enclosed herewith.

In the Unitherm process, precooked whole muscle turkey breasts and other products are removed from their cooking bags and are preferably then first conducted through a continuous infrared oven solely for the purpose of melting accumulated purge material from and drying the product surface. The product is then dipped in or deluged with liquid smoke or other browning liquid and conveyed through a browning oven. To Applicant's knowledge, all uses of this browning process heretofore have also involved the use of an intervening chilling step after browning and prior to packaging.

The infrared purge removal and drying step of the Unitherm browning process has been used solely for melting purge and drying the surface and has not been performed for the purpose of, and is not effective for, surface pasteurization. Moreover, the infrared oven used for the purge removal procedure includes only upper infrared elements. The oven includes no elements positioned under the conveyor belt for irradiating the bottom of the product. In addition to being unnecessary for the purge removal process, the positioning of infrared elements beneath the belt would pose a serious safety hazard because the lower elements would ignite the purge material as it drips from the product.

#### IN THE UNITED STATES DISTRICT COURT

	FOR THE WESTERN DIST	RICT OF OKLAHOMA
(1)	UNITHERM FOOD SYSTEMS, INC., an Illinois corporation; and	
(2)	JENNIE-O FOODS, INC., a Minnesota corporation,	AUG 1/9 2002 )  MORERT D. DENNIS, CLERK  U.S. DIST. COURT, WESTERN DIST. OF CA
	Plaintiffs,	
<b>v.</b>		) No. CIV-01-347-C
(1)	SWIFT-ECKRICH, INC. d/b/a CONAGRA REFRIGERATED FOODS, a Delaware corporation,	) ) )
	Defendant.	DOCKETED

#### ORDER

On September 14, 1999, the United States Patent and Trademark Office ("PTO") issued Patent No. 5,952,027 (the "'027 patent") to Prem S. Singh ("Singh"). Mr. Singh filed the '027 patent application with the PTO on May 11, 1998. Mr. Singh subsequently assigned the '027 patent to Defendant Swift-Eckrich, Inc., d/b/a/ ConAgra Refrigerated Foods ("ConAgra"). Plaintiffs Unitherm Food Systems, Inc., and Jennie-O Foods, Inc. ("Unitherm"), have moved this Court to invalidate the '027 patent.

ConAgra, for its part, asks the Court to dismiss the Plaintiffs' causes of action numbered eight (tortious interference with existing contractual and business relations), nine (intentional interference with prospective economic relationships), ten (actual or constructive fraud), eleven (violation of the Sherman Antitrust Act), and twelve (violation of the

Oklahoma Antitrust Reform Act). Due to prior Court Order and/or stipulations of dismissal between the parties, a grant of summary judgment for Defendant on the above causes of action would leave the Plaintiffs with one remaining cause of action - a declaration by this Court that U.S. Patent 5,952,027 (the "027 patent") is invalid and unenforceable.

The Plaintiffs' claim of invalidity and unenforceability is discussed first, as it is from this Court's decision on the validity of the '027 patent that the other claims flow.

#### A. Plaintiffs' Motion for Partial Summary Judgment

#### 1. Patent Validity

"Under 35 U.S.C. § 282, a patent is presumed valid and one challenging its validity bears the burden of proving invalidity by clear and convincing evidence." Mas-Hamilton Group v. Lagard, Inc., 156 F.3d 1206, 1216 (Fed. Cir. 1998). The Court has previously presumed the '027 patent valid in the hands of its inventor (and assignee) and refused to order a requested transfer of inventorship. However, that does not mean that the patent is indeed valid, it is only presumed so.

Section 102 of U.S.C. Title 35 provides, in relevant part:

A person shall be entitled to a patent unless -

\* \* \*

(b) the invention was . . . described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of the application for patent in the United States.

Plaintiffs claim that the process disclosed in the '027 patent was on sale and/or in public use in the United States prior to May 11, 1997, and the patent is therefore invalid and unenforceable. To prove their assertion, Plaintiffs must show either "a definite sale or offer for sale of the claimed invention prior to the critical date" or a "public use" of the invention prior to the critical date. Pfaff v. Wells Electronics. Inc., 124 F.3d 1429, 1433 (Fed. Cir. 1997). aff'd, 525 U.S. 55 (1998). Here, the critical date is May 11, 1997.

Plaintiffs maintain that David Howard of Unitherm is the true inventor of the process at issue, and that he offered the process for sale prior to May 11, 1997, even repeatedly offering it to the Defendant. From the papers submitted, and as more fully discussed belw, it is clear to the Court that David Howard and Unitherm indeed offered a process for sale as early as 1993. However, the question for the Court is whether the process offered by Mr. Howard was identical to the process in the '027 patent. Thus, the Court must examine not only the papers submitted by the parties, but also the patent itself. However, Defendant has objected on admissibility grounds to each of the nearly 80 exhibits attached to the Affidavit of David Howard ("Howard Affidavit") submitted by Plaintiffs in support of their motion. Defendant has moved to strike each of these exhibits. Therefore, before considering them in the context of these motions, the Court must first decide whether the exhibits are admissible.

However, for the purpose of this motion only, Plaintiffs concede that the process was invented by Defendant, but argue that for this issue it is immaterial.

40.0-12-05 t2:30 tknw:tabber

#### 2. Admissibility

Defendant objects to the exhibits attached to the Howard Affidavit on authentication/hearsay grounds. The Court discusses each of these bars to admissibility in turn below. The motion to strike is contained solely in footnotes to Defendant's response brief. The Court condemns this practice, but, rather than delay the case by requiring the filing of a separate motion and brief, the Court now decides the motion.

#### a. Authentication

Fed. R. Evid. Rule 901(a) states, in relevant part

The requirement of authentication . . . as a condition precedent to admissibility is satisfied by evidence sufficient to support a finding that the matter in question is what its proponent claims.

Rule 901(b)(1) renders Defendant's objections frivolous as the exhibits are attached to, or are in actuality, sworn affidavits of a "witness with knowledge" that the documents are what they are claimed to be. *Id.* Further, the Amended Howard Affidavit submitted with Plaintiffs' Reply brief remedies any arguable failings of the initial Affidavit. Thus, the Court finds that the documents attached to the Howard Affidavit are properly authenticated.

#### b. Hearsay

Defendant also attacks many of the exhibits as inadmissible hearsay. Fed. R. Evid. 801. However, the Court agrees with the Plaintiffs' contention that the exhibits fall under the "business records exception" to the hearsay rule found in Fed. R. Evid. 803(6). The Court also agrees that not only are the records of one's own business excepted from the

hearsay rule, but also records received from other businesses, where, as here, the requirements of Fed. R. Evid. 803(6) are met. *United States v. Johnson.* 971 F.2d 562, 571 (10<sup>th</sup> Cir. 1992). The Court finds that the authenticated exhibits attached to the Howard Affidavit fall under a hearsay exception and are admissible. Thus, the Defendant's Motion to Strike is hereby DENIED.

Having dispensed with the evidentiary objections, the Court now discusses the exhibits submitted by the Plaintiffs to ascertain what "process" may have been developed by David Howard, and what he offered for sale prior to May 11, 1997.

#### 3. Unitherm's "Process"

From the submitted exhibits the Court finds that Unitherm was attempting to sell ovens along with its process for browning and/or smoking muscle meats as early as 1993. Prior to May 11, 1997, the process consisted of the following:

Removing purge material from a pre-cooked whole muscle meat product using hot water, drying the rinsed product prior to applying browning and/or smoking agent by either rapidly conveying the rinsed product through a circulating air oven at 350°C for less than one minute or by using the first zone of the oven for drying and then applying a browning and/or smoking agent between the first and second zones. Browning and/or smoking the product over a range of temperatures (from about 250°C to 350°C) to obtain a spectrum of colors, with product shrinkage of as little as 1% or less. Liquid smoke, Maillose, turkey broth, other flavorants and combinations thereof at overall concentrations of about 20-100% are used.

Some solutions comprising mixtures of broth and Maillose or liquid smoke have broth concentrations of 5%, 10%, and higher. Appendix G, Unitherm's Response to Interrog. Nos. 1, 8; Appendix E, Howard Aff., Exh. 11.

A promotional video ("the Proctor/Unitherm video") filmed September 14, 1993, in Elk Grove, Illinois, includes demonstrations of pre-cooked, whole muscle turkey breasts and hams being, or which have been, dipped in a Maillose or liquid smoke solution and then conveyed through a RapidFlow oven. These products are shown beside a pre-cooked turkey breast that was taken out of the cooking bag and washed and dried, as were the other products, but was not dipped or browned. The video notes that a spray station can be added between oven zones for smoking, flavoring, or enhancing product browning. Appendix E, Howard Aff. ¶ 14-18, Exhs. 12A-G, 13, 81.

Importantly for this case, the Unitherm process was demonstrated to Syed Hussain, who was present on behalf of Defendant, at a "test" conducted on September 30, 1993, at Unitherm's facility. Plaintiff's Brief at 8, citing Appendix B, Defendant's Answer ¶ 14. Defendant admits that the "tests" involved applying Maillose to the surface of a fully cooked turkey breast and then conveying the breast through a RapidFlow circulating air oven at 280-300° C for 7 minutes. *Id.* 

Unitherm data dated October 14, 1993, indicates "five different runs" were made at the behest of Defendant with dip times of one minute in solutions ranging from 50% to 5%. "Internal core temperatures were all 36° F (2° C) or less, with none increasing more than 3°

F (1-1/2 C). Yields of up to 98.7% were obtained." Plaintiff's Brief at 9; citing Howard Aff., Exh. 25. Defendant argues that the "runs" were made in the interest of Unitherm selling, not a process, but ovens to Defendant. In fact, Defendant alleges that it had earlier disclosed the process at issue to Unitherm. Plaintiffs' Brief at 9; citing App. B, Def's. Answer ¶ 12-14. However, this assertion is belied by the testimony of Messrs. Hussain and Singh - that they do not know how Unitherm "derived the concept of using liquid browning agent or liquid smoke in conjunction with the RapidFlow oven to brown whole muscle turkey products." Plaintiffs' Brief at 9 n. 6, citing App. J, Singh Dep. pp. 146-47; App. X, Hussain Dep. pp. 115-16, 158.

From October 26 to December 1, 1993, copies of the Proctor/Unitherm video were distributed, primarily by mail and at trade shows, throughout the industry. Transmittals and related letters accompanying the videos variously discuss: "the next generation of turkey browning systems;" successful uniform browning using Maillose; yields of 98-99%; processing times under eight minutes; application of Maillose by drenching, submersion, or between cooking zones; "the 'browning' process;" and an internal temperature rise of less than 1°C. *Id.*, Howard Aff., Exhs. 15-20. One letter states that the items in the video were processed in about seven minutes. *Id.*, Exh. 18.

Unitherm did not, and never intended to, patent the process at issue.

#### 4. Summary Judgment Standard

Summary judgment is appropriate if the pleadings and affidavits show there is no genuine issue as to any material fact and that the moving party is entitled to judgment as a matter of law. Fed. R. Civ. P. 56(c). "[A] motion for summary judgment should be granted only when the moving party has established the absence of any genuine issue as to a material fact." Mustang Fuel Corp. v. Youngstown Sheet & Tube Co., 561 F.2d 202, 204 (10th Cir. 1977). The movant bears the initial burden of demonstrating the absence of material fact requiring judgment as a matter of law. Celotex Corp. v. Catrett, 477 U.S. 317, 322-23 (1986). A fact is material if it is essential to the proper disposition of the claim. Anderson v. Liberty Lobby, Inc., 477 U.S. 242, 248 (1986).

The critical question here is whether there is clear and convincing evidence that Defendant patented a process on May I1, 1998, that was on sale and/or in public use before May I1, 1997. As stated above, if the answer is affirmative, the Defendant's patent is invalid and unenforceable. The Court must first construe the claims of the '027 patent to discern whether Mr. Singh should have been barred from patenting this invention.

#### 5. Claims

In order to assess the "metes and bounds" of a patent, it is the Court's role to interpret and construe the patent's claims. Markman v. Westview Instruments, Inc., 52 F.3d 967, 970, 997 (Fed. Cir. 1995). "When a court construes the claims of the patent . . . the court is defining the federal legal rights created by the patent document." Id. at 978. As repeatedly

stated by the Federal Circuit and the Supreme Court, the Court is the sole arbiter of claim construction. See Markman at 977. "To ascertain the meaning of claims, [the Court] consider[s] three sources: the claims, the specification, and the prosecution history." Markman at 979, quoting Unique Concepts, Inc. v. Brown, 939 F.2d 1558, 1561 (Fed. Cir. 1991). "[I]deally there should be no 'ambiguity' in claim language to one of ordinary skill in the art that would require resort to evidence outside the specification and prosecution history." Markman at 986. In this case the prosecution history of the '027 patent has not been submitted; thus, the Court relies solely on the claims and the specification for its construction of the '027 patent claims.

The Court has been made aware of a recent case, Juicy Whip, Inc. v. Orange Bang, Inc., 292 F.3d 728 (Fed. Cir. 2002), where the court held that Orange Bang did not "present substantial evidence satisfying its clear and convincing burden of proof that it ... practiced" a "complete embodiment[] of the claimed invention." Id. at 738. The court further stated the general proposition that "oral testimony of prior public use must be corroborated in order to invalidate a patent." Id. at 737-38. Here, because of the Court's ruling that the submitted documentary evidence is admissible, there is voluminous corroborating evidence accompanying the deposition testimony in this case. Thus, the Court's task is to discern whether Unitherm practiced a complete embodiment of the invention claimed in the '027 patent prior to May 11, 1997.

AUG-19-02 15:32 FRUM: F00041

The '027 patent includes 36 claims (2 independent and 34 dependent) and is entitled:

Method for Browning Precooked, Whole Muscle Meat Products. The first independent claim

(1) is for:

A process for browning precooked, whole muscle meat products comprising: coating a browning liquid pyrolysis product onto at least a portion of the surface of a precooked whole muscle meat product; and then exposing the coated surface to an energy source and selectively heating the coated surface of the whole muscle meat product at a temperature and for a time sufficient to develop a golden-brown color on the exposed surface, without substantial shrinking the precooked, whole muscle meat product.

'027 patent, col. 8, ll. 4, 14...

The rest of the claims are variations on the theme of Claim 1, utilizing different heat source temperatures (about 60° C. - about 290° C.), core meat temperatures (less than 5° C. - 13° C.), shrinkage (less than 1 - 4 wt. %), products (turkey, chicken, fish), browning liquid pyrolysis products (hardwood, sugar, dextrose), amount of browning product (.05 - 1.0 wt. %), masking agents or flavoring enhancing compositions, utilizing turkey flavor and/or broth in the browning liquid pyrolysis product (.5 - 15 wt. %), and energy sources (circulating air oven, impinging air oven, laser light, medium wavelength energy infra red radiation or microwave radiation). The Plaintiffs' chart of the parallels between the Unitherm process and the '027 patent succinctly demonstrates that the two "inventions" are one and the same. Plaintiffs' Brief at 28. Thus, the Court finds that the '027 patent describes the Unitherm process prior to May 11, 1997.

Defendant's only rebuttals are disputed interpretation of the claim terms "golden brown" and "browning liquid pyrolysis product," and that David Howard never publicly used or offered the Unitherm process for sale. These are discussed in turn below.

#### 6. Golden Brown

To begin, the '027 patentee did not act as his own "lexicographer" and failed to specifically define the term "golden brown." Rexnord Corp. v. The Laitram Corp., 274 F.3d 1336, 1342 (Fed. Cir. 2001), 2001 U.S. App. LEXIS 24810, \*11 ("patent law permits the patentee to choose to be his or her own lexicographer by clearly setting forth an explicit definition for a claim term that could differ in scope from that which would be afforded by its ordinary meaning"). Thus, the Court views the term "golden brown" with its plain meaning to one of skill in the art. Talbert Fuel Sys. Patents Co. v. Unocal Corp., 275 F.3d 1371 (Fed. Cir. 2002), 2002 U.S. App. LEXIS 241 \*7, supra. "Golden brown" is defined as "a variable color averaging a strong brown that is yellower and slightly darker than gold brown, yellower and paler than average russet, and yellower and less strong than rust." Webster's Third New International Dictionary, 975 (1986).

Defendant argues that "a determination of 'golden brown' under the '027 Patent necessitates a Hunter-Lab Color Meter measurement of the L, A and B values of that product." Defendant's Response at 40. Defendant further asserts that examples in the specification limit the term golden brown to color measurements ranging from L=48.9-53.2; A=9.6-14.3; and B=29.8-39.9. However, "courts cannot alter what the patentee has chosen

to claim as his invention. . . limitations appearing in the specification will not be read into claims, and . . interpreting what is means by a word in a claim 'is not to be confused with adding an extraneous limitation appearing in the specification, which is improper." (emphasis in original). Intervet America, Inc. v. Kee-Vet Labs., Inc., 887 F.2d 1050, 1053 (Fed. Cir. 1989), quoting E.I. Du Pont De Nemours & Co. v. Phillips Petroleum Co., 849 F.2d 1430, 1433 (Fed. Cir. 1988). "[C]ourts do not rework claims. They only interpret them." Id., quoting Autogiro Co. of America v. United States, 384 F.2d 391, 395-96 (Ct. Cl. 1967). The Court has "set forth the asserted claim[] in full above and it is clear that [it] make[s] no reference whatever to [limiting "golden brown" to LAB color measurements]." Id. at 1055.

The Court thus disagrees with Defendant's unsupported assertion that "golden brown" is defined in the '027 patent. The Court finds that the specification only makes clear that the inventors used language such as: "The following examples are included to further illustrate the invention. They are not limitations thereon" (emphasis added). '027 patent, col. 5, ll. 48-49. The patentee had every opportunity to define by limit the term "golden brown" and chose not to do so. The Court finds that the closest thing to a definition of golden brown in the '027 patent appears at col. 1, ll. 15-18, "consumers place a premium on precooked, whole muscle meat products that have the same golden brown color . . . as their home-cooked counterparts." The Court further finds that documents submitted by Plaintiffs, e.g. Howard Aff., Exhs. 1E, 44C, and 44F, clearly encompass a "golden brown" product.

AUG-19-02 15:33 FRUM:FORDAL

Finally, Defendant's expert in sensory evaluation declares that "no system or test has been used to verify that the color computer printouts attached . . . to Plaintiffs' Motion . . . accurately reflect the color of a product with certain L, A and B values." Defendant's Response. Exh B, p. 2. However, because the Court finds that LAB values do not limit the term golden brown in the '027 patent, the assertion is irrelevant.

#### 7. Browning Liquid Pyrolysis Products

Defendant also claims that Plaintiffs misconstrue the phrase "browning liquid pyrolysis product" by relying on the application of liquid smoke. Defendant states that there are a number of liquid smoke products that do not promote browning and those products are thus not browning liquid pyrolysis products as defined in the '027 patent. The Court finds that the term is not, as Defendant asserts, defined in the '027 patent. Second, the Court notes that there are other pyrolysis products which do not promote browning. However, it is undisputed that Unitherm sometimes used a browning liquid smoke product, which is a browning liquid pyrolysis product. Importantly, Unitherm's process also uses Maillose as a browning agent. Maillose is not liquid smoke but is undisputedly also a browning liquid pyrolysis product. The Court finds it enough that at least two such browning liquid pyrolysis products, as called for in the '027 patent, were used.

#### 8. Public Use/On-Sale Bar

In Pfaff v. Wells, supra, the Supreme Court elucidated a two-part test for an on-sale bar. 1) the product must be the subject of a commercial offer for sale; and 2) the invention

AUG-13-62 15:33 FRUMIFSDDG1

must be ready for patenting. 525 U.S. at 67-68. Here, the Plaintiffs have stated undisputed facts which show, as a matter of law, that the Unitherm process was on-sale and ready for patenting as early as 1993. The Defendant argues that it did not sell or use the process in the '027 patent prior to the application cut-off date. While that may be true, the undisputed fact is that it was demonstrated and offered by Unitherm for sale to the Defendant. Therefore, the fact that it wasn't Defendant who made a public use or sale of the process is irrelevant. Even if Mr. Singh did invent the process at issue, it was unpatentable due to Unitherm's offer for sale prior to May 11, 1997. The correspondence between Unitherm and the Defendant establishes this finding as their co-existence in relation to a potential sale of the Unitherm process goes back at least to 1993.

Further, the fact that Unitherm sold its process to Hudson Foods and that Hudson Foods had product, produced by the Unitherm process, on the market by April 1997 is undisputed. Plaintiffs' Brief, Exh. N. Defendant stresses that Unitherm sold Hudson an oven, not a process. Hudson's representative claims that the process was in fact Hudson's and they purchased Unitherm's oven because, "they [Unitherm] had an oven... that would do this [in-line smoking and/or browning] better in this particular application." Exh. N at 159. It is undisputed that the "basic process [utilized by Hudson] was the same [as David Howard's]. Exh. N at 244. "[T]he primary change... was the addition of a conveyor system that took it through a [RapidFlow] oven." Id.

The Court finds Hudson's test data to reveal that after purchasing and utilizing Unitherm equipment, Hudson practiced a complete embodiment of the invention claimed in the '027 patent in February, 1997. See Exh. N at WB-000081-85. For illustration, the Court inserts the Hudson data parenthetically within Claim 1 of the '027 patent:

A process for browning precooked, whole muscle meat products (breasts) comprising: coating a browning liquid pyrolysis product (liquid smoke, MAILLOSE from 45 seconds to 70 seconds) onto at least a portion of the surface of a precooked whole muscle meat product, and then exposing the coated surface to an energy source (Unitherm 3-zone RapidFlow oven) and selectively heating the coated surface of the whole muscle meat product at a temperature and for a time sufficient to develop a golden-brown color (299° C. - 354° C. at 7m. 48 s. - 9m 30s. resultant colors from "dark" to "golden brown with black highlights")<sup>2</sup> on the exposed surface, without substantial shrinking (1.7 - 3.16%) the precooked, whole muscle meat product.

'027 patent, col. 8, 11. 4-14.

The Court finds the above to be clear and convincing evidence that the Unitherm process, patented by the Defendant, was on-sale and in use (by perhaps more than one company), prior to May 11, 1997.

Defendant repeatedly stresses to the Court that Unitherm's attempts to sell its process were confidential and thus not public. The Defendant misapplies the law of public use. The

The Court notes that the temperature of 299° C. is higher than the upper range of 290° C. in the '027 patent. However, the Court also notes that the temperature in Example 1 of the '027 patent was 570°F, which converts to a temperature of 299° C. Further, the process offered for sale by Unithern utilizes oven temperatures ranging from 250°-350° C. The undisputed "key" to the process of in-line browning and/or smoking is a calculus of temperature over time that results in the desired golden brown end-product.

purpose of the public use bar is "to require inventors to assert with due diligence their right to a patent through the prompt filing of a patent application." LaBounty Mfg. v. U.S. Intern. Trade Com'n, 958 F.2d 1066, 1071 (Fed. Cir. 1992) (emphasis added). Defendant correctly asserts the proposition that "third party secret commercial activity . . . [should not act as] a [public use] bar [against ConAgra]." Woodland Trust v. Flowertree Nursery, 148 F.3d 1368. 1371 (Fed. Cir. 1998). This is to protect patentees from losing their patent rights when a third party has also practiced the invention at issue, without the patentee's knowledge. This is not the case here. It is undisputed that employees for Defendant were aware of the technology as early as 1993. It is also undisputed that Hudson Foods purchased technology from Unitherm in February 1997, and a mass mailing of videos and associated correspondence, regardless of David Howard's expectations of secrecy, resulted in the public distribution and offer for sale of the Unitherm process. It is absurd to argue that the technology was somehow "secret." See OddzOn Prods., Inc. v. Just Toys, Inc., 122 F.3d 1396, 1402 (Fed. Cir. 1997) ("secret prior art [is] art that has been abandoned, suppressed, or concealed"). The undisputed facts establish, as a matter of law, that "secret" prior art does not exist in this case and does not bar application of § 102(b).

The Court has closely examined the voluminous documentation submitted in connection with the present motions and concludes that the Defendant's patent describes a process that was both on sale and in public use prior to May 11, 1997. Thus, the Court finds the 1999 issuance of the '027 patent was in error. Because the Court finds the '027 patent

:

to be invalid and unenforceable, it is not necessary to discuss the Plaintiffs' allegations of Defendant's fraud on the Patent Office. The Court now examines the remaining causes of action in turn, as the Defendant has moved for summary judgment on each.

#### B. Defendant's Motion for Summary Judgment

#### 1. Anitrust Violations

Defendant argues that the two Plaintiffs' antitrust claims cannot succeed for different reasons: 1) Unitherm is not a competitor of the Defendant in the market for sliceable cooked turkey products; and 2) Jennie-O cannot show any antitrust injury as a result of any action of the Defendant. The Court agrees only with the latter and discusses each argument separately below.

#### a. Unitherm

The Sherman Act § 2 states, in relevant part:

"Every person who shall monopolize, or attempt to monopolize, or combine or conspire with any other person or persons, to monopolize any part of the trade or commerce among the several States...shall be deemed guilty of a felony."

#### 15 U.S.C. § 2.

The offense of monopoly under § 2 of the Sherman Act has two elements: (1) the possession of monopoly power in the relevant market, and (2) the willful acquisition or maintenance of that power as distinguished from growth or development as a consequence of a superior product, business acumen, or historic accident. *United States v. Grinnell Corp.*, 384 U.S. 563, 570-71 (1966).

The Clayton Act states, in relevant part:

"[A]ny person who shall be injured in his business... by reason of anything forbidden in the antitrust laws may sue therefor... without respect to the amount in controversy, and shall recover threefold the damages by him sustained..."

15 U.S.C. § 15.

Con Agra argues that Unitherm cannot succeed on its antitrust claims because Unitherm is not a competitor of Con Agra and thus has no antitrust standing. The Court finds that the law is not as Con Agra argues it to be.

In Walker Process Equip. v. Food Mach. & Chem. Corp., 382 U.S. 172 (1965), the Supreme Court held that "the enforcement of a patent procured by fraud on the Patent Office may be violative of § 2 of the Sherman Act provided the other elements necessary to a § 2 case are present. In such event the treble damage provisions of § 4 of the Clayton Act would be available to an injured party." Id. at 174.

ConAgra denies that it is a competitor of Unitherm, claiming that ConAgra processes meat while Unitherm sells ovens. But it is undisputed that ConAgra offers a browning/smoking process at a royalty of 10¢ per pound and Unitherm offered its browning/smoking process for sale as early as 1993. And ConAgra's own documents previously produced in this action also support the conclusion that ConAgra is a competitor of Unitherm and that ConAgra is enforcing its patent.

Others in the industry may approach your company regarding this patent, and we would appreciate it if you would inform them

that we intend to aggressively protect all of our rights under this patent.

Plaintiffs' Brief in Opposition, Exhibit 9 (Letters from ConAgra to 15 prospective purchasers of the Unitherm system).

This Court has already found the reference to "others in the industry" sufficient to put Unitherm under apprehension of a lawsuit for patent infringement — something which has since come to fruition with the filling of ConAgra's counterclaim. The fact that ConAgra has asserted a counterclaim for patent infringement on an invalid patent makes Unitherm's antitrust claim a viable one. Walker Process, 382 U.S. 172. The issue yet to be decided is whether ConAgra fraudulently obtained the patent. See Walker Process, supra. Thus, the Court finds that the undisputed facts are sufficient to withstand the motion for summary judgment on Unitherm's antitrust claims.

#### b. Jennie-O

ConAgra next argues that Jennie-O's antitrust claims must be dismissed because Jennie-O cannot show antitrust injury. Jennie-O's theory of antitrust recovery differs from that of Unitherm. Jennie-O alleges a right to seek injunctive relief for prospective damage under § 16 of the Clayton Act. *Hawaii v. Standard Oil Co.*, 405 U.S. 251, 260-61 (1972), permits suit for threatened damage;

<sup>&</sup>lt;sup>3</sup> Because the Court has upheld Unitherm's antitrust causes of action under federal law, a discussion of the Oklahoma Antitrust Reform Act ("OARA") 79 Okla. Stat. § 205, is unnecessary. See 79 Okla. Stat. § 212 ("[OARA] shall be interpreted in a manner consistent with Federal Antitrust Law, 15 U.S.C. § 1, et seq. and the case law applicable thereto").

[Section] 16 of the Clayton Act, 15 U.S.C. § 26 which provides for injunctive relief [states, in relevant part]: "Any person, firm, corporation, or association shall be entitled to sue for and have injunctive relief, in any court of the United States having jurisdiction over the parties, against threatened loss or damage by a violation of the antitrust laws... when and under the same conditions and principles as injunctive relief against threatened conduct that will cause loss or damage is granted by courts of equity, under the rules governing such proceedings...."

Here, Jennie-O alleges that enforcement of fraudulently obtained monopoly rights in the '027 patent by requiring a 10¢ per pound royalty would "drive Jennie-O out of business." However, because the '027 patent is invalid, Jennie-O's standing to participate in a cause f action for prospective injunctive relief due to Defendant's alleged violations of the antitrust laws is moot. Jennie-O cannot be driven out of business by a competitor attempting to charge royalties on an invalid patent.

#### 2. Tortious Interference with Existing Contractual or Business Relations

Under Okiahoma law, "one has the right to carry on and prosecute a lawful business in which he is engaged without unlawful molestation or unjustified interference from any person, and any malicious interference with such business is an unlawful act and an actionable wrong." Crystal Gas Co. v. Oklahoma Natural Gas Co., 1974 OK 34, 529 P.2d 987, 989.

To recover damages for the tort of malicious interference with a business relationship, a plaintiff must show:

1. That he or she had a business or contractual right that was interfered with.

- 2. That the interference was malicious and wrongful, and that such interference was neither justified, privileged nor excusable.
- 3. That damage was proximately sustained as a result of the complained-of interference.

Mac Adjustment, Inc. v. Property Loss Research Bureau, 1979 OK 41, 595 P.2d 427, 428.

Defendant correctly asserts that there must be more to a business relationship than speculation on the part of David Howard that he could have begun business relationships with new purchasers of the Unitherm process. The Court finds that Unitherm has not adduced material facts, other than the self-serving and unsubstantiated testimony of David Howard, that place this cause of action in dispute. Indeed, Unitherm has not expressly responded to this portion of Defendant's brief, instead arguing a right to proceed on its claim of Intentional Interference with Prospective Economic Advantage. Thus, the cause of action for Tortious Interference with Existing Contractual or Business Relations must fail.

#### 3. Interference with Prospective Economic Advantage

The parties' briefs treat the tort of interference with business relations as synonymous with the tort of interference with prospective economic advantage. "This comparison is not entirely accurate. Although both torts do have similarities, the underlying theories of liability differ. Interference with a prospective economic advantage usually involves interference with some type of reasonable expectation of profit, whereas interference with a contractual relationship results in loss of a property right." Overbeck v. Quaker Life Ins. Co., 1984 OK CIV APP 44; 757 P.2d 846, 847-48. Taking all circumstances in their totality, the Court

finds that there exist enough disputed facts to support this cause of action through the summary judgment stage.

It is undisputed that once the '027 patent issued, the Defendant mass mailed an arguably threatening letter throughout the industry. It is also the testimony of Robert Wood of Jennie-O that this letter had, at the least, a chilling effect on any further possibility of Unitherm selling its products to Jennie-O. Plaintiffs' Brief, Exh. 5, pp. 74-76. The Court thus finds that the cause of action for interference with prospective economic advantage is not susceptible to summary judgment.

#### 4. Actual or constructive fraud

Defendant claims that Unitherm cannot prove fraud because Unitherm has failed to identify a material omission or misrepresentation made by the Defendant to Unitherm. The Court disagrees and denies summary judgment on this cause of action.

#### The Court notes that:

Oklahoma follows the view that fraud can be predicated upon a promise to do a thing in the future when the intent of the promisor is otherwise. This principle is an exception to the general rule that for a false representation to be the basis of fraud, such representation must be relative to existing facts or those which previously existed, and not as to promises as to future acts. The gist of the rule is not the breach of promise but the fraudulent intent of the promisor at the time the pledge is made not to perform the promise so made and thereby deceive the promisee. There is a wide distinction between the nonperformance of a promise and a promise made mala fide, only the latter being actionable fraud.

AUG-13-02 15:35 PRUM:PDDD&+

Citation Co. Realtors, Inc. v. Lyon, 1980 OK 68, 610 P.2d 788, 790-91 (emphasis added), citing State ex rel. Southwestern Bell Telephone Co. v. Brown, 1974 OK 19, 519 P.2d 491.

Unitherm claims that ConAgra promised to consider the purchase of the Unitherm process which was first shown to ConAgra in 1993, and ConAgra then stole the process and patented it for its own use. ConAgra vigorously disputes this claim. The undisputed facts are that the Defendant considered purchasing Unitherm's technology and failed to do so. Under Oklahoma law, the disputed fact that the Defendant may have subsequently stolen Unitherm's technology supports a cause of action for breaching a promise to consider a purchase. The Court DENIES summary judgment on this count.

#### CONCLUSION

As discussed more fully above, Defendant's Motion to Strike is hereby DENIED.

Plaintiffs are GRANTED partial summary judgment on their third cause of action and their sixth and seventh affirmative defenses to Defendant's Counterclaim (Patent Invalidity and Unenforceability). Plaintiffs are entitled to a judgment declaring the '027 patent invalid and unenforceable.

Defendant is GRANTED summary judgment on the Plaintiffs' eighth cause of action (tortious interference with existing contractual and business relations). Defendant is also GRANTED summary judgment on Jennie-O's antitrust claims.

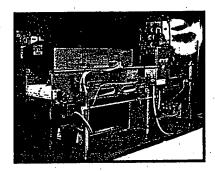
Defendant's Motion for Summary Judgment is denied on remaining causes of action. i.e., intentional interference with prospective economic relationships, actual or constructive fraud, violation of the Sherman Antitrust Act (Unitherm only).

Finally, this ruling moots the Defendant's motion to strike Jennie-O's second affirmative defense of non-infringement, or, in the alternative, for partial summary judgment of infringement. A judgment will enter at the conclusion of these proceedings.

IT IS SO ORDERED this 19th day of August, 2002.

CHIEF UNITED STATES DISTRICT JUDGE

# Smoking & Browning under 10 minutes!



S

S

i,

ľ

:d

at id

1-

y ie id

ng

·p-

by

in-

ьe

.er

:ad

ors

ual

ays one

an-

:115-

iors fety otato

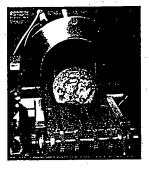
poultry

drumettes

hicken

#### Liquid Smoke Application

Liquid smoke is sprayed onto product, covering all surfaces equally. Sophisticated recovery and reuse system drastically reduces waste of liquids.



### RapidFlow II Continuous Convection Oven

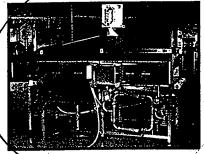
High velocity, high temperature air quickly raises surface temperature for fast color formation.

Because only the surface is affected, minimal cooling is needed before repackaging.



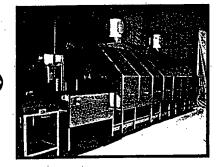
The UNITHERM bag stripper can handle up to 10,000 pounds of cooked turkey breasts per hour.

Automated system removes bag and depth controlled blades slit casings with minimum scoring



Infrared Purge Removal

Turkey breasts are conveyed through a 1200 degree chamber which melts any purge and dries the surface of the product, dramatically improving adhesion of liquid smoke for more consistent color.



#### UNITHERM

FOOD SYSTEMS, INC.

1108 West Hartford. Ave. Ponca City, Oklahoma 74601
Tel: (580) 762-0197 Fax: (580) 762-0199
e-mail: unitherm@unithermfoodsystems.com
Visit our web site: www.unithermfoodsystems.com

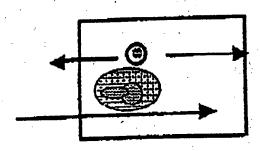
Telephone: 405 -762-0197

## -UNITHERM BULLETIN

Jpdate on browning and cooking in the Rapidflow Oven

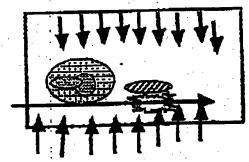
## BROWNING IN TRADITIONAL CONTINUOUS OVENS Up and down or sideways only?

Conventional convection oven wisdom says there are only two types of linear continuous Convection ovens, featuring either horizontal or vertical air flows, as illustrated in the diagrams below. Vertical air flow is usually called "impingement" and it represents current state of the art in cooking.



75 <u>00</u>

HORIZONTAL AIR FLOW OVEN



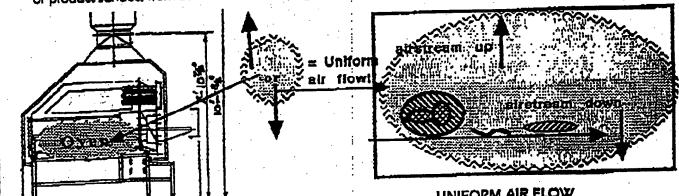
VERTICAL AIR FLOW OVEN

turbulence =

It's generally acknowledged horizontal air cooks much slower and less efficiently than vertical air. However, high velocity air, 'Impingement,' – at its most efficient – it too turbulent for many products. Is there an alternative?

#### UNITHERM'S RAPIDFLOW: THE MISSING LINK

There is a third convection oven cooking method, a uniform, circulating air stream, that is a perfect thermal atmosphere for rapid, uniform browning or cooking of any product. This diagram shows how air is gently circulated at low velocity, maintaining precise and uniform temperatures for any type of product or product surface, from bacon and link sausages to whole birds.



UNIFORM AIR FLOW circulating airstream at low velocity

Diagram shows unique air flow pattern, featuring precise temperature and "thermal condition" control throughout the oven cooking chamber.

The only adjustments required on the oven are the zone temperatures in each module and steam condition. Air stream and circulation are engineered for each module and any product that's processed.

Vertical and horizontal air flows have obvious limitations in processing, related to product size and configuration in terms of optimum air handling conditions. The Rapidflow is the most universal and simplest of the continuous convection overs.

625.98

© Morgan-Grampian Books Ltd.

HEMICAL AND PROCESS ENGINEERING SERIES

# in Food Processing Infra-red Radiati Application of

PROFESSOR A.S.GINZBURG

Translated by

A. GROCHOWSKI

Silauldolanad With The The Sendlaulsen

C.R.C.PRESS CLEVELAND

1969

Paper supplied by Frank Grunfeld (Sales) Ltd.

PRODUCED BY UNEOPRINT set on electric hayboards photo-reproduced and printed offset ol The Greeham Press UNWIN BROTHERS LIMITED Old Wohlng Survey England

Bound by Mansell (Bookbinders) Ltd., London

293

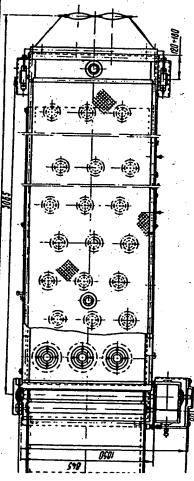


Fig. 160 A thermo-radiant installation for the drying of the TAL (calcium tartrate);

l- drive frame, 2- jacket (casing), 3- charging bunker, 4- speed regulator, 5- housing, 6- (insulating) jacket, 7- infrared radiation lamp, 8- exhaust pipe, 9- doors, 10- discharging bunker, 11- guides with agitators, 12- supporting grate, 13- conveyor, 14- conveyor drive.

# THERMAL TREATMENT AND DRYING OF MEAT AND MEAT PRODUCTS

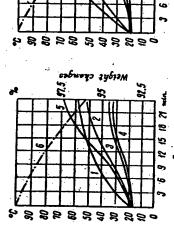
t was comparatively recently that use was made of infra-red radiation in he meat industry.

n 1949, the experimental department of the Kiev Fish Combine carried out irst experiments on the curing of meat and sausage meat and related proucts, which gave encouraging results. The drying of meat products in 1888 experiments was accomplished by infra-red rays.

N. E. Fedorov, I. A. Rogov, A. V. Gorbatov, E. E. Afanasov, A. E. Golovkin, and V. V. Fomenko of the Process and Apparatus Department of the Moscow Technological Institute of the Meat and Dairy Industry, carried out studies of the application of infra-red radiation in the thermal treatment and drying of meat products. It was stressed in their account that the application of radiant heating resulted in a large reduction of the time required for the thermal treatment, and made it possible to create continuous production streams in the meat industry enterprises. It was considered desirable to apply infra-red radiation, in the first place for the drying in the process of curing of meat products, and secondly in the manufacture of skinless sausage products.

The experimental installation at the above Meat and Dairy Institute (MTIMDI for short) was used for the study of the thermal treatment of raw salted brisket. A 50 mm. thick sample of the meat was suspended between two vertically-positioned radiating panels. The distance between the latter could be adjusted. The framework of the panel was made from angle-iron, and the faces were made from sheet steel, 2.5 mm. thick. The panel was heated by an electric spiral element.

In order to study the temperature field of the sample, five thermo-couples were installed in it (see the diagram in Fig. 161). The temperature curves shown in Fig. 161 describe the heating of meat at the panel temperature of 300°C, the air rate between the panels of 0.5 m./sec. and the distance between the panels 250 to 140 mm. The same figure shows the plots of the changes in the weight of the sample over time. At the distance between the panels of 250 mm., the duration of the treatment was 24 min. and the decrease in the weight was 3.3 per cent, while at the distance of 140 mm.—21 min. and 4.1 per cent, respectively.



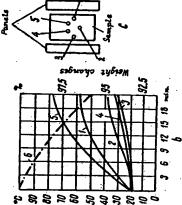


Fig. 161 Temperature curves describing the heating of meat and plots of the changes in the weight of the sample over time.

294

Drying and Thermal Treatment of Food Products by Infra-red Rays 295

denth (point 5), were heated more intensely than the surface layer (point 1) It can be seen from the plots, that the meat layers positioned at a greater cold air. The fat layer (points 3 and 4) is heated up more slowly, because evidently results from the cooling of the surface layer by the circulating particularly when the distance between the panels was decreased. This of the relevant optical characteristics of the fat.

The process of curing involves subjecting the products to infra-red radiation twice before smoking treatment, and afterwards.

s then passed through the chamber 7, where the heating by lamp radiators charge opposite to the charge of the smoke particles. The smoked product to the chamber 3, to be preliminarily dried by the lamp radiators 4. Next, he product is directed to the smoking chamber 6, to which smoke from a charge window I, is suspended on a cable conveyor, 2, which transports it smoking of bacon (U.S.A.). The meat, introduced through the charge-dissmoke-generator is introduced. An intensive deposition of smoke on the surface of the product, takes place in this chamber, the product having a nelps to attach the film of the smoking substances on the meat surface. Fig. 162 presents an outline diagram of an installation for the electro-The product is cooled on its route to the discharge window

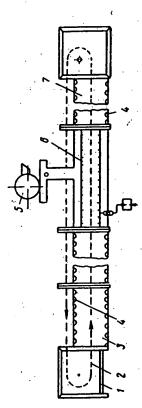


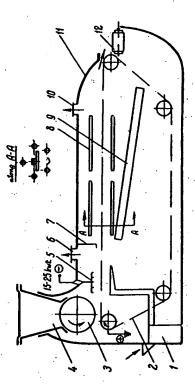
Fig. 162 An outline diagram of an industrial installation for the electrosmoking of bacon.

9 min., at the weight decrease of 1.5 to 2 per cent. In the electro-smoking weight, while the duration of the heating (drying) after the smoking is 7 to preliminary drying before the electro-smoking (using metallic panels) is bacon, and brisket in the electro-smoking installation results in an overamount to 1.0 to 2.5 per cent. The treatment of the 'koreika' (gammon), According to data from N.E. Fedorov, I.A. Rogov, et al., duration of the 10 to 15 min., at the weight reduction by 2 to 3 per cent of the starting process, evidently on account of self-vaporization, the weight losses all weight decrease of 5 to 6 per cent.

nside 250-300°C, the long-wave infra-red rays penetrate the product to a These investigators consider that at a temperature of the radiating panel

depth of 1-1.5 mm. According to the U.S.A. sources, the application of curing installations with lamp radiators, not only cuts the costs of the treatment, but also lowers product losses to 1 per cent.

Nichrome spirals. These radiating elements were provided with reflectors The heat treatment of force-meat by infra-red radiation to obtain skinless evaluated as the sources of infra-red radiation: ceramic panels heated by sausage products, was carried out at the MTIMDI. An outline diagram of electricity, quartz gas-filled tubes having a tungsten spiral, and the open for the quartz one, 1200°K for the open spiral, and 721°K for the ceramic from polished aluminium, of a parabolic shape (the parabola equation of  $y=0.0312\,x^2$ ). The recorded temperature of the radiators was: 2060 K the experimental installation is shown in Fig. 163. The following were panel.

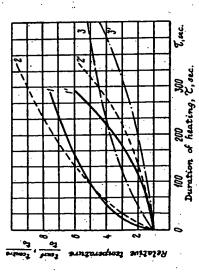


trough for the broth and fat given-off by the force-meat during the heat treatment, 10- flue, 11- the shell of the instal-Fig. 163 Outline diagram of the installation for the radiant heating of system of high-voltage ionization,  $6-\log a$  (partial) exhaust skinless sausage products. I — smoke-generator, Z — conpiston (26  $\times$  26 mm.) 4 - bunker for the force-meat, 5 - the reyor, 3 - rotor made from a vinyl plastic material, having for spent gases, 7 - baffle, 8 - infra-red radiators, 9 lation, 12 — receiving transporter.

ready for use, as compared with 3 to 5 min. required for the spiral radiators. The drawback of the horizontally-positioned, open spirals was their Ceramic panels have high heat inertia, and it takes 2 hr. to get the panel sagging, when heated.

The process of thermal treatment was terminated at the temperature of the central layer of the product of 60 to 70°C.

Fig. 164 presents plots characterizing changes over a period of time of the relative temperatures of the surface  $(t_{\rm surf})$  and the central  $(t_{\rm centre})$  layers, when heated by different radiators. Plots designated by numbers by heating with the open spirals, while the temperature of the central layer while the curves designated by numbers having dashes (apostrophe marks) indicate the changes in tentre values. It is characteristic for the quartz radiators, that the temperature of the surface is lower, than that obtained without dashes show the changes in  $\frac{t_{\text{Surf}}}{t}$  ( $t_{\text{O}}$  is the initial temperature), increases more rapidly. This confirms that the short-wave radiation  $\lambda_{max} \approx 1.4 \ \mu$  penetrates deep into the product.



products by different radiators: 1 - quartz radiators; Temperature curves for heating skinless sausage - open spirals; 3 - ceramic panels. Fig. 164

meat formed rotationally was higher than that of meat formed by the continuous nozzle method, as a result of the rougher surface obtained by the The authors of the above study observed that the absorptivity of forceformer method. During thermal treatment, the surface of the product darkens considerably, and this also helps to increase its absorptivity



the preliminary drying by infra-red lamps of 100 watt power was in this infra-red radiation in the manufacture of dry sausages. The duration of M. Déribéré reported encouraging results obtained in the application of case 1 hr., instead of 24 hr. required in ordinary drying.

Drying and Thermal Treatment of Food Products by Infra-red Rays

tubular quartz radiators, at the density of the radiant stream equal to 2.2 volt/cm. (measured by a thermo-pile), and at the pan loading of 9 kg. salted water, while the other batch was subjected to infra-red radiation by Canadian investigators utilized the infra-red radiation in the blanching of meat in the preparation of the meat stew. A comparison was made of the results of blanching cubes of near-to-fillet frozen meat (about  $25 \times 25 \times$ 25 mm.), where one batch of the cubes was boiled in two volumes of

it was found, that the duration of treatment was 6 min. and the weight losses pectively, in the infra-red radiation method. However, in the process of the 30 per cent in the scalding procedure, and only 5 min and 15 per cent, resblanched meat and 340 g. of the meat stew), the weight losses were: for the sterilization at 116°C for 110 min. and the storage for 1.5 months at room blanched by infra-red radiation was of better quality than the boiled meat. boiled meat 5 per cent, and for the meat prepared by infra-red blanching noted, that in respect of the aroma, coloration, and consistency, the meat 20 per cent, i.e. the total losses were approximately the same. It was temperature in 452 gram (1 lb.) tins (each of which contained 112 g.

# 13. THERMAL TREATMENT AND DRYING OF FISH

sect of the flavour and in general terms, were obtained. Best results were Good results were obtained in the application of infra-red radiation in the less than twofold to threefold, while high quality indicators, both in resish-processing enterprises. The duration of drying was shortened not those obtained in the intermittent conditions of the irradiation.

other countries. Thus, in the U.S.S.R. the infra-red radiation is applied: in the pilchards in oil (an industrial plant fitted with ceramic panels and external the electro-smoking of fish, which in the last 15 years have been introduced in the U.S.S.R., France, the U.S.A., Great Britain, East Germany, Poland and spirals at the Kiev Refrigeration base); in the canning of smoked Caspian canning of hot-smoked fish; sprats and sardines (a semi-industrial plant The infra-red radiation is successfully utilized in the modern plants for reatment of bream and sea bass (an experimental conveyer installation litted with lamp radiators and an industrial plant fitted with radiating Nichrome spirals at the Astrakhan Fish Combine); and in the thermal fitted with lamp radiators at the Moscow Fish Combine). The first work on the curing of fish was carried out by the Kiev Fish Com-Sciences, and the All-Union Scientific-Research Institute of Fisheries and institute of General and Inorganic Chemistry of the Ukrainian Academy of Oceanography, acting on the recommendations of M. I. Kalitina and A. A. Kalitin. A summary of this work was compiled by I.S. Pavlov and A.A. bine jointly with the Klev Technological Institute of Food Industry, the Voskresenskii.

The electro-smoking (curing) is carried out in three stages: the preliminary drying of fish, the smoking itself, and boiling.

### Infra-Red Radiation for Food Processing II. Calculation of Heat Penetration During Infra-Red Frying of Meat Products

Magnus Dagerskog\*

SIK - The Swedish Food Institute, Fack, S-400 23 Göteborg (Sweden) (Received November 7, 1978; Accepted January 9, 1979; Iwt 588)

Infra-red frying experiments with slices of beef and pork were accomplished by the use of two different radiator systems with emission maximum at 1.24 µm and 3.0 µm respectively. The experimentally measured temperature distribution during frying was compared with the corresponding temperature distribution calculated from the developed mathematical model of the combined infra-red and convection heating. Influence of crust formation on reflectance was measured, indicating higher reflectance values for the fried than for the raw samples. The pork also showed higher reflectance than the beef. Fat cover increased the reflectance of the raw product to some degree.

With the developed computer program the influence of different processing variables such as product thickness, air temperature, infra-red energy flux and type of infra-red radiator were studied. A simulated comparison between infra-red frying and contact frying showed that the infra-red flux had to be about 50% higher to give the same surface temperature development. Frying time then became 50% shorter for a thickness of 14 mm.

MOTICE: This material may be protected by copyright law (Title 17 U.S. Code)

### Introduction

The basic concepts of infra-red radiation are high heat transfer capacity, heat penetration directly into the product and fast regulation response. These qualities indicate that infra-red radiation should be an ideal source of energy for frying purposes. As distinguished from microwave heating, the penetration characteristics are such that a suitable balance between the surface and body heating can be reached which is necessary for an optimal frying result.

Some empirical work in this field can be found in the literature and may serve as a background to heat penetration calculations. Early tests with tube heaters (1) revealed that successful radiant cooking requires that both the quality and quantity of energy used be in proper balance. Radiant heating elements should preferably operate at color temperatures between 1200 and 1800°C as only the waves below 2 µm are effective in developing color. Successful results were reported for the following frying applications.

- 1. Frying fish sticks. In operation, products were heated on one side at a time after passing a curtain of cooking oil.
- Deep fat frying of breaded chicken. The system involves 2 to 3 minutes deep fat frying in peanut oil followed by a 12 minute exposure in an IR-oven.
- Browning roast beef hash. The meat is loaded into stainless-steel pans and ran through the oven on an 18 minutes cycle to brown the surface.
- Braising ham slices. One side of the 12 mm thick ham slices are browned in 18 minutes.
- 5. Broiling hamburgers in 7 minutes
- 6. Pre-cooking sausage links in 3-5 minutes.

ASSELBERG, MOHR and KEMP (2) used quartz tube heaters (1000–1300°K) at 2.2 watts per cm<sup>2</sup> for braising meat for beef stew. At a similar degree of heat treatment, the infrared treatment required shorter cooking time (83%) with lower weight losses (50%) than for the parboiling procedure. The flavor, color and texture of the infra-red braised meat was claimed to be much superior.

An industrial process for pre-cooking of bacon in a continuous infra-red oven at Swift & Company was reported by HLAVACEK (3). The 288 kilowatts of overheat infra-red radiant heating from quartz lamps was supplemented by electric resistance heaters below the seamless, stainless steel belt. Frying time was 2-3 minutes, and pre-cooked bacon tasted as good as or better than freshly fried bacon.

Several studies of Soviet investigators have been reported concerning frying meat by infra-red radiation, but the only work published in English is that of BOLSHAKOV et al. (4), on the production of baked pork meat products. By analysing transmittance spectrograms of lean pork they showed that maximum transmission of infra-red radiation falls in the region of 1.2 μm. For wavelengths longer than 2.5 μm, the transmission capacity was negligible. Consequently it was necessary to use sources with maximum radiation falling in the region of maximum transmission to achieve deep heating of pork. For heat treatment of the product surface radiators in the region of minimum transmittance and reflectance  $(\lambda_{\text{max}} > 2.3 \, \mu\text{m})$  had to be used. The authors therefore designed a two-stage frying process. In the first stage surface heat transfer is brought about by radiant flux with  $\lambda_{max}$  at 3.5 to 3.8 µm. In the second stage the product is subjected to infrared radiation flux with \( \lambda\_{max} \) at 1.04 \( \mu m \), providing deep heating of the product. The results showed that the final moisture content and sensory quality of the products heated

<sup>\*</sup> Present address: Nordreco AB, \$-26700 Bjuv, Sweden.

by the two-stage process were higher than these heated by conventional methods.

The objective of this second part of our study was t use our determinations of infra-red absorption data in part one in the development of a computer program for the calculation of heat transfer during infra-red frying. To verify the model, comparisons with practical frying experiments were carried ut.

### Material and Methods

### Raw material

Pork (68% water content), cut into 13 mm thick slices and beef from the semimembranosus muscle (74% water content), cut into 11 mm thick slices were used.

### Temperature measurement

During the frying experiments, the temperature at the two surfaces (0.5 or 2 mm deep) and at the centre were registered by means of thin Cu-Konstantan thermocouples (0.25 mm glass fiber insulated wires). The thermocouples were positioned inside the meat samples according to the procedure of BENGTSSON, JAKOBSSON and DAGERSKOG (5).

### Frying equipment

with

: was

rined

ilues

ce of

lure.

!tact

ube

iing

the

vith.

ıre.

eat

ıu-

bу

:ed

by

eel

ed

ıly

i),

b:

16

An infra-red oven was designed to allow double-sided heating on a leaning stainless steel net, so that the drip losses would not fall on the infrared radiators (Fig. 1). Interchangeable modules were provided with two alternative types of infra-red radiators:

- 1. Quartz tube heaters (Philips 1kW, type 13195X). Filament temperature is 2340°C at 220 V rating, corresponding to  $\lambda_{max}$  of 1.24  $\mu m$ . Each module is fitted with 4 tubes of this type.
- Tubular metallic electric heaters (Backer 500 W, type 9N5.5). Tube temperature is 680°C at 220 V, corresponding to λ<sub>max</sub> of 3.0 μm. Each module consisted of 8 tubular heaters.

A white ceramic material (Kauwool, Höganäs) with a reflectance capacity of 80–90% was used as reflector in the modules. An important property of the reflector material was its selfcleaning capacity. To regulate the energy flux at the surface of the product, the distance between the heaters and the product was variable (5–15 cm). The actual energy flux was measured in separate heating experiments, using a black reference body of copper.

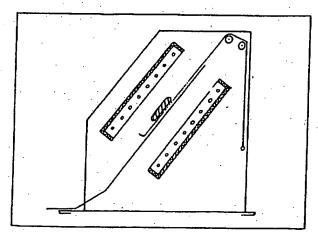


Fig. 1 The infra-red oven with interchangeable radiator modules used in the frying experiments

Speciral refleciance measurements

The procedure and equipment is identical with that described in part I (9)

Mathematical model for the heat penetration calculations
To calculate temperature distribution during combined infrared and convection heating, the heat conduction equation was solved numerically using the finite difference method (7). The infinitesimal differentials are then replaced by differences of finite size and the degree of accuracy of the representation is determined by the step size of these differences. The explicit solution is restricted by the following stability criterion (8):

$$\Delta t \leq \frac{\Delta x^2}{2 \cdot a \left(1 + \alpha \cdot \frac{\Delta x}{\lambda}\right)}$$

For the calculation of the heat generated by the infra-red radiation an exponential penetration was assumed:

$$P_{n+1} = P_n \cdot \exp(-S \cdot \Delta x)$$

The equations are further described in Fig. 2.

The results in part I (9) indicated a sharp boundary between the high penetration of the short wave radiation (<  $1.25 \mu m$ ) and the low penetration capacity of the long wave radiation (<  $1.25 \mu m$ ). In the program these are separated and the mean values of the absorbed energy are calculated independent of each other:

$$P_{\text{total}} \xrightarrow{P_{< 1.25 \ \mu m}} (1 - R_{< 1.25 \ \mu m})$$

### Result and Discussion

Influence of crust formation on reflectance

By the use of a double-sided contact fryer (6), 15 mm thick slices of pork and beef were fried 0.5, 1.0, 1.5, 2.0 and 3.0 minutes at 200°C pan temperature. Measurement of surface reflection between 0.8 and 2.3 µm was made after cooling to room temperature. The mean values of two separate measurements are shown in Fig. 3 for reflectance at 1.1 µm, indicating higher reflectance values for the fried than for the raw samples, in spite of the dark crust color formed. The pork showed higher reflectance than the beef. Fat cover increased the reflectance of the raw product as expected. The corresponding spectra for the raw, raw plus fat and fried samples (1.5 minutes) are plotted in Fig. 4 and 5. The appearance of the spectra are in good agreement with those of the other food products presented in part I(9). For the calculation of heat penetration it is necessary to know the mean reflectance in the short wave ( $< 1.25 \mu m$ ) and long wave ( $> 1.25 \mu m$ ) regions in relation to the emission spectrum of the used infra-red radiator.

This was done by integrating the reflectance spectrum in steps of  $0.1 \mu m (\Delta x)$  as follows:

$$R = \frac{\sum R_{\Delta x} \cdot E_{\Delta x}}{\sum E_{\Delta x}}$$

 $R_{\Delta x}=\%$  reflectance of the product in the increment  $\Delta x$   $E_{\Delta x}=\%$  emission of the radiator in the increment  $\Delta x$ 

The results for the two products and infra-red radiators are shown in Tab.1.

Tab. 1 Calculated mean reflectance and energy distribution for the two infra-red radiat rs used in experiments

Radiation source	Mean : Pork	reflecta	nce (%) Beef		Energy dis- tribution (%)	
	<1.25 µm	>1.25 µm	<1.25 μm	>1.25 µm	<1.25 μm	>1.25 μm
$\lambda_{\text{max}} = 1.24  \mu\text{m}$	54.3	10.0	42.6	7.7	25.8	74.2
$\lambda_{max} = 3.0 \mu m$	47.6	6.9	39.7	5.0	0.2	99.8

Comparison between experimental and simulated temperature distribution

The infra-red frying experiments were carried out under the conditions shown in Tab. 2. In Fig. 6 and 7 the measured time temperature curves at the surface and centre of the meat slabs are shown. The corresponding results of the computer simulations of temperature distribution, for mean values of product thickness, are also presented in Fig. 6 and 7. The dissipation coefficient (S) for pork (4.2 cm<sup>-1</sup> at < 1.25 μm and 35.2 cm<sup>-1</sup> at > 1.25 μm), found in part I, (9) was also used for the beef. A thermal conductivity (λ) value of 0.40 J/m,s, °C was utilized according to BENGTSSON, JAKOBSSON and DAGERSKOG (5), together with a thermal diffusivity (a) value of 1.38 10<sup>-7</sup> m²/s. The temperature of the air surrounding the products ranged from 40 to 100 °C during the experiments and was set to 70 °C during computer simulation in combination with a heat transfer coefficient (α)

Fig. 2 The principal equations of the finite difference solution to the heat transport by combined conduction and infrared radiation

of 20 J/m<sup>2</sup>,s. °C. Due to the expansion of the meat during frying, the calculated temperature rise was somewhat slower in the first and faster in the last part of the frying process than that experimentally determined. However, the agreement between the experimental and calculated curves is quite good.

Tab. 2

Mean

Produ. thicku.

(mm;

- befo

- afte:

frying

Initia

temp

Dens

at pro

(Wic

Computer simulation as a tool for process calculations. With the developed computer program the influence of different processing variables on the resulting heat penetration into slabs of pork was studied. The following variable list was used as a basis for the simulations.

Thickness: 10, 12, 14, 16, 18 mm

Initial temperature: 5°C

Air temperature: 20, 70, 150, 250°C Heat transfer coeff.: 20 J/m<sup>2</sup>,s, °C IR-flux: 0, 1, 2, 3, 4 W/cm<sup>2</sup>

IR-radiator (λ<sub>max</sub>): 1.0, 1.12, 1.24. 1.8, 3.0 μm Dissipation coeff.: 4.2 and 35.2 cm<sup>-1</sup> resp. Reflected radiation: 54.3 and 10.0% respectively

For the standard values, the temperature profiles in Fig. 8 were obtained, showing the influence of the two separate wavelength regions.

The influence of product thickness is shown in Fig. 9 and of air temperature in Fig. 10. As seen, the air temperature has a very small effect on the centre temperature lapse in contrast to the infra-red flux in Fig. 11. Above 3 W/cm² there is, however, no further large gain in centre temperature results from increasing flux density. Surprisingly, very little difference between the different infra-red radiators, simulated in Fig. 12, was noted for 14 mm thickness. This depends on the

n= 1 2 3 n-1 n n+1	ns-1 ns ns+1
$T_1$ $T_2$ $T_3$ $T_{n-1}$ $T_n$ $T_{n+1}$	$T_{ns-1}$ $T_{ns}$ $T_{ns+1}$
SURFACE 1	SURFACE 2
$\Rightarrow P_2 P_3 P_{n-1} P_n P_{n+1}$	Pns Pns+1
PT w/ $m^2$ R <sub>2</sub> R <sub>3</sub> R <sub>n-1</sub> R <sub>n</sub> R <sub>n+1</sub>	R <sub>ns</sub> R <sub>ns+1</sub> $\rightleftharpoons$ RT w/ m
For $n=2$ to $n=ns$ : $T_{n,k+1}=T_{n,k}+a \cdot \frac{\Delta t}{\Delta x^2} (T_{n+1,k}-2T_{n,k}+T_{n-1,k}) +$	
	where T = temperature (°C)
$\frac{a \Delta t}{\lambda \Delta x} \left[ PT(P_n - P_{n+1}) + RT(R_{n+1} - R_n) \right]$	n = space increment subscript k = time increment subscript PT, RT = total density of radiation at the product surface (W/m²)
For n=1 and n=ns+1: $T_{1,k+1}=T_{1,k}+2 \cdot a \cdot \frac{\Delta t}{\Delta x^2} (T_{2,k}-T_{1,k}) +$	P, R = distribution of radiation due to internal adsorption  \[ \Delta \text{ = time increment (s)} \] \[ \Delta \times \text{ = space increment (m)} \] \[ a = \text{ thermal diffusivity (m²/s)} \]
$2 \cdot a \cdot \frac{\alpha}{\lambda} \cdot \frac{\Delta t}{\Delta x} \left( T_{arr} - T_{1,k} \right) + \frac{2a \cdot \Delta t}{\lambda \cdot \Delta x} \left[ PT(1 - P_2) + RT(R_2 - R_1) \right]$	λ = thermal conductivity (1/m, s <sub>1</sub> °C) α = heat transfer coefficient (1/m <sup>2</sup> , s, °C)

at during at slower process agreearves is

ens of difetration list was

n Fig.8 eparate

and of re has a ontrast nere is, results differated in on the

Tab. 2 Experimental conditions during infra-red frying. Mean values of tw separate measurements.

	Pork		Beef	
	λ <sub>max</sub> = 1.24	μm . λ <sub>mar</sub> = 3.0 μm	λ = 1.2	pm 1 = 3.0 pm
Product thickness (mm)		· .		
- before	13	13	11	11/2
– after frying	15	16	13	14
Initial temp. (°C)	10.0	7.5	6.0	6.0
Density of re at product su				
(W/cm²)	3.0	2.6	2.2	1.9

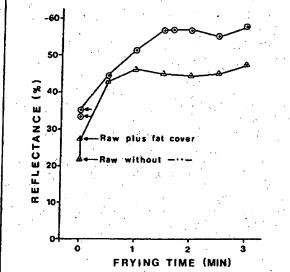


Fig. 3 Reflectance as a function of frying time for pork (6) and beef (a) measured at a wavelength of 1.1 µm

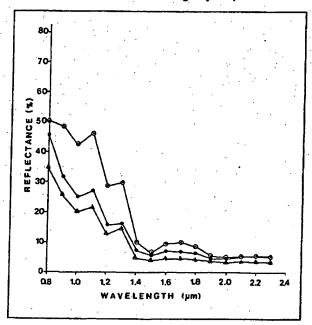


Fig. 5 Reflectance spectrum of raw (a), raw plus fat covered (a) and fried (a) 15 mm thick slices of beef

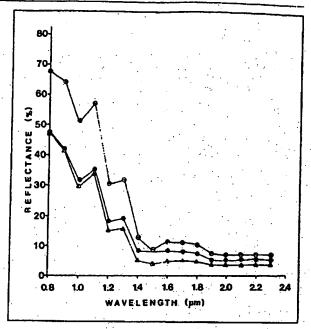


Fig. 4 Reflectance spectrum of raw (a), raw plus fat covered (b) and fried (c) 15 mm thick slices of pork

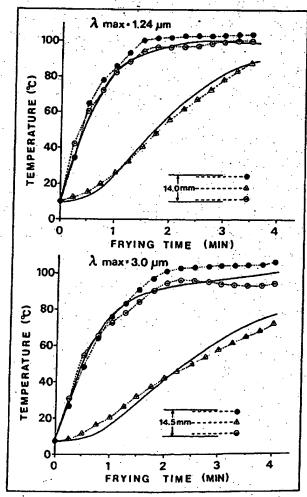


Fig. 6a, b Experimentally determined (----) and computer simulated \_\_\_\_) time-temperature curves during infra-red frying of slices of pork by two different infra-red radiators. The surface temperatures are measured at 0.5 mm depth

100-

80

60

40-

100

60-

40

EMPERATUR

TEMPERATURE

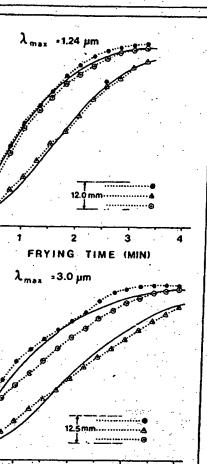


Fig. 7a, b Experimentally determined (----) and computer simulated (\_\_\_) time-temperature curves during infra-red frying of slices of beef by two different infra-red radiators. The surface temperatures are measured at 2 mm depth

2

FRYING TIME (MIN)

3

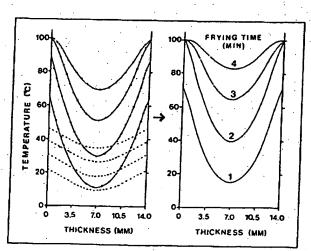


Fig. 8 Calculated temperature profiles during infra-red frying with quartz tube heaters ( $\lambda_{max} = 1.24 \mu m$ ) at 2 W/cm<sup>2</sup>. ---- short wave radiation ( $\lambda < 1.25 \mu m$ )  $\approx 26\%$ 

•-•-- long wave radiation ( $\lambda > 1.25 \mu m$ )

total radiation

combined effect of increasing penetration capacity and body reflection as the wavelength maximum of the radiator decreases. The figure also indicates the maximal centre temperature development during contact frying.

A simulated comparison between infra-red frying and contact frying in Fig. 13 sh ws that, due t the penetration capability, the infra-red flux density has to be about 50% higher to give the same initial surface temperature development as for contact frying. Frying time to 73°C then becomes 50% shorter during infra-red frying than during double-sided contact frying.

### Conclusions

A mathematical model was proposed based on measurement of penetration properties and spectral reflectance described in part I (9). By the use of a computer program, heat penetration calculations during combined infra-red and convection heating was successfully compared with experimental measurements of temperature development. Process calculations showed strong influence of product thickness and infra-red flux on the rate of heating, while the temperature of the surrounding air and type of infra-red radiator showed minor influence.

Further development of the model seems to be possible if the concepts of body reflection, as described in part I, are introduced. Thereby the need of integrating the reflectance spectra would be eliminated and a less empirical model found.

Fig.

fryi:

Fig.

tem

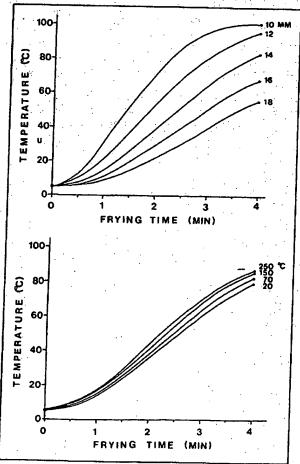


Fig. 9 Influence of thickness on the time-temperature lapse at the centre of the product during infra-red frying
Fig. 10 Influence of air temperature on the time-temperature lapse at the centre of the product during infra-red frying

≈ 74%

100%

hody liator tem-: concapanigher ent as . 50% : con-

m nt. ribed peneavec-·ental .culanfraof the minor : if the

nodel

intro-

tancé



ipse at & rature

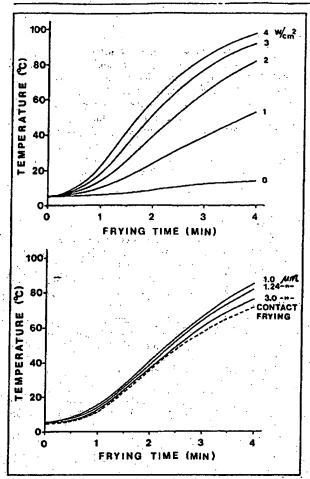


Fig. 11 Influence of infra-red flux density on the time-temperature lapse at the centre of the product during infra-red frying

Fig. 12 Influence of type of infra-red radiator on the timetemperature lapse at the centre of the product during infra-red frying. Comparisons are also made with contact frying

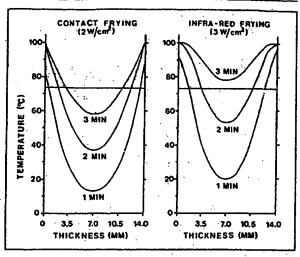


Fig. 13 Comparison between contact and infra-red frying at equal initial surface temperature development

### References

- 1 ANON, Food Eng., 30, 110 (1958) 2 ASSELBERGS, E.A., MOHR, W.P. and KEMP, J.G., Food tech-
- nol., 14, 449 (1960)
  HLAVACEK, R.G., Food Proc., 28, 51 (1968)
  BOLSHAKOV, A.S., BORESKOV, V.G., KASULIN, G.N.,
  ROGOV, F.A., SKRYABIN, U.P. and ZHUKOV, N.N., Paper J5,
- 22nd European meeting of meat research workers, 1976. BENGTSSON, N.E., JAKOBSSON, B. and DAGERSKOG, M., J. Food Sci., 41, 1047 (1976)
- DAGERSKOG, M. and BENGTSSON, N.E., Lebensm.-Wiss. ii. -Technol., 7, 202 (1974)
- ROSENBURG, D.U., Methods for the numerical solution of partial differential equations, Am. Elsevier Publishing Co., New York, 1969,
- p.18. 8 HOLLMAN, J.P., Heat Transfer, Mc Graw-Hill, New York, 1963,
- p. 103.

  9 DAGERSKOG, M. and ÖSTERSTRÖM, L., Lebensin.-Wiss. u. -Technol., 12, 237 (1979)

## AND FOOD PRODUCTS HEAT TRANSFER

## BENGT HALLSTRÖM

Food Engineering Chemical Center, University of Lund, Sweden

# CHRISTINA SKJÖLDEBRAND

SIK-The Swedish Institute for Food Research, Gothenburg, Sweden

## CHRISTIAN TRÄGÅRDH

Food Engineering Chemical Center, University of Lund,

ELSEVIER APPLIED SCIENCE LONDON and NEW YORK

ELSEVIER APPLIED SCIENCE PUBLISHERS LTD Crown House, Linton Road, Barking, Essex 1G11 8JU, England

Sole Distributor in the USA and Canada ELSEVIER SCIENCE PUBLISHING CO., INC. 52 Vanderbilt Avenue, New York, NY 10017, USA

WITH 20 TABLES AND 114 ILLUSTRATIONS...

© ELSEVIER APPLIED SCIENCE PUBLISHERS LTD 1988

British Library Cataloguing in Publication Data

Hallström, Bengt Heat transfer and food products. 1. Food, Effect of heat on 2. Food—

Composition

I. Title II. Skjöldebrand, Christina II. Trägårdh, Christian

Library of Congress Cataloging in Publication Data

Hallström, Bengt, 1924-Heat transfer and food products

Includes index.

Food industry and trade.
 Heat—Transmission.
 Skjöldebrand, Christina.
 Trägårdh, Christian.
 Title.

TP370.5.H35 1988

ISBN 1-85166-130-1

property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. No responsibility is assumed by the Publisher for any injury and/or damage to persons or

Special regulations for readers in the USA

photocopies of parts of this publication may be made in the USA. All other copyright questions, including photocopying outside the USA, should be referred to the publisher. Massachusetts. Information can be obtained from the CCC about conditions under which This publication has been registered with the Copyright Clearance Center Inc. (CCC), Salem,

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

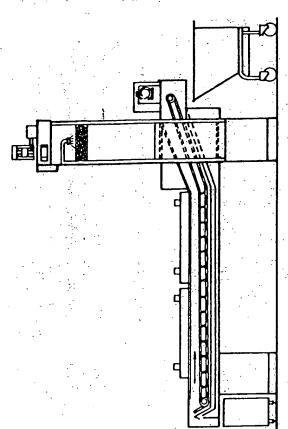


Fig. 5.35. Deep fat fryer used in the food industry.

deep fat fryer may differ from small oil baths to large continuous frying baths in industry. Figure 5.34 shows a small deep fat fryer for catering. The product is placed in small net cages that are lowered into the bath. Figure mportant that the product is completely covered by fat. The size of the 5.35 shows a diagram of a deep fat fryer used in the food industry. A conveyer belt transports the product through the bath. The product is often pushed through the bath by means of paddles or another arrangement.

Products that are deep fat fried may be divided into two groups:

- frying process, i.e. pommes frites, potato crisps, fried scampi, bacon Products that get their characteristic feature from the deep fat
- Products that were originally fried in a pan or baked in an oven, i.e. meat balls, hamburgers, chicken, fish.

It is very important to handle the fat correctly and to choose the right fat quality for deep fat frying. In principle, there are three different types of fat that may be used:

- Liquid vegetable oils
  - Solid vegetable fats
- Fats of animal origin 4 6

## THERMAL PROCESSING EQUIPMENT

Fat used for frying foods has to fulfil the following demands:

- -The melting point has to be below 37°C in order not to cause an unpleasant feeling in the mouth.
- -The taste has to be neutral.
- -The fat has to be able to be kept at frying temperature for a long time. (A foam is formed when the fat is too old, due to polymerization and oxidation products.)

The lat has to have a high smoking temperature.

### nfrared ovens

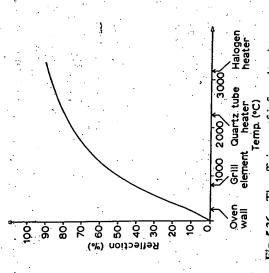
neating result. Some empirical work in this field can be found in the literature, e.g. the work of Ginzburg,79 and may serve as a background to successful radiant cooking required that both the quality and quantity of energy used should be suitably balanced. The following four factors are The basig characteristics of infrared radiation are high heat transfer capacity, heat penetration directly into the product and fast regulation source of energy for heating purposes. As distinguished from microwave heat penetration calculations. Early tests with tube heaters revealed that surface and body heating can be reached which is necessary for an optimal esponse. These qualities indicate that infrared radiation should be an ideal heating, the penetration characteristics are such that a suitable balance for most critical for an optimum heating result, Radiator temperature. The temperature of the IR radiator determines the spectral distribution of the emitted radiation and also the maximum IR radiation flux that can be achieved.

### Radiator efficiency

energy losses due to cooling of the surrounding material. The cooling effect All radiators emitting IR radiation at elevated temperatures suffer from

Some data for different IR radiators Table 5.9

IR radiator	$\lambda_{max}$ $(\mu m)$	Temp. (K)	Maximum energy flux (kW/m²)	Size factor at constant flux
Ultra-short-wave	1:0	2 627	4010	-
Short-wave	1.12	2316	2 547	9-1
Short-wave	1.24	2066	1 697	2.4
Medium-wave	<u>~</u>	1 338	382	10.5
Long-wave	30	. 694	20	80.9



The efficiency of infrared emitters. Fig. 5.36.

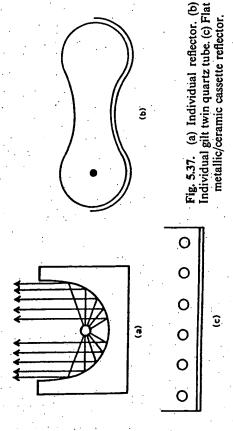
surrounding the heating filament with a quartz tube, thus reducing the radiator efficiency. Here it is assumed that a high reflection ratio means a high efficiency if the reflected energy is absorbed by the product. Table 5.9 depends on the size and construction of the radiator as well as the reflector system. In high-temperature IR radiators the cooling effect is reduced by convective losses. Figure 5.36 indicates some realistic figures for IR gives some data for different IR radiators.

## IR reflection/absorption properties

important to construct the oven/reflector system in an optimal way to As discussed earlier (in Chapter 2), the reflectance of food materials is remember this fact in order to choose the right type of IR radiator. It is also generally high (50%) at short wavelengths (<1.25  $\mu$ m). It is important to reduce potential energy losses.

### IR penetration properties

penetration capacity is around 10 times higher than for long wavelengths order to optimize the system. For short wavelengths ( $<1.25 \mu m$ ) the It is important to know the IR penetration properties of food materials in (>1.25  $\mu$ m), as discussed in Chapter 2. The direct penetration capacity of IR adiation into food materials makes it possible to increase the energy flux



without burning the surface, thus reducing the heating time compared with convectional heating methods. This is especially true for thin products.

### Infrared oven construction

in many countries. The main component—the radiator—may be of various Rovens of various sizes and constructions have been developed and tested ypes and shapes. Radiators can be divided into the following main groups:

- Gas-heated radiators (long-wave)
  - Electrically heated radiators
- -tubular/flat metallic heaters (long-wave)
  - -ceramic heaters (long-wave)
- -quartz tube heaters (medium- and short-wave)
- —halogen heaters (ultra-short-wave)

Various reflector systems are also used (Fig. 5.37);

- -Individual metallic/gold reflectors
  - -Individual gilt twin quartz tube
- -Flat metallic/ceramic cassette reflector

belt, which is usually a wire mesh, as indicated in Fig. 5.38. Some ovens also Some of the high-intensity radiators require water or compressed air continuous type. The radiator cassettes are positioned above the transport use IR heating from below, if the product allows this from a contamination point of view. The oven shown in Fig. 5.39, used in reheating and frying in atering, utilizes individual pans for the product to avoid fat dripping. In cooling to avoid overheating. IR ovens may be either of batch or

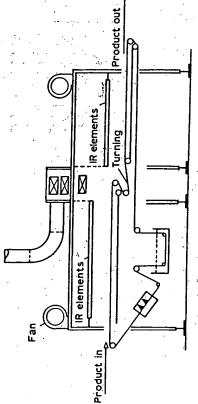


Fig. 5.38. Continuous-process infrared oven.

on/off system where the number of radiators/tubes operating at any one lime is controlled by switches. Microcomputer control systems, for other ovens the IR system is combined with air convection to control the heating is controlled by thyristor systems. The simplest way is to use a pure sequence control, etc. have also been utilized. The main advantages over surrounding air temperature and humidity. In most ovens the degree of convection ovens are:

- -Very short heating time
- -Fast heating due to penetration of radiation into the product
- -Easy to pre-program and regulate the heating cycle for different products
- -High energy efficiency

## Experience with infrared ovens

Most experience of IR ovens is outside the food area, e.g. the drying of acquer and printing ink. Most experience within the area of food comes

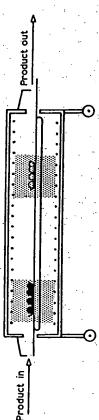


Fig. 5.39. Infrared oven in which heating is from above and below the product; this oven utilizes individual pans for the product.

## THERMAL PROCESSING EQUIPMENT

Ginzburg has reported several areas of application where positive results from the USA, USSR and the eastern European countries. In later years SIK has done basic work on applying this technique within the area of food. The main part of this work is still of an experimental nature. have been obtained:79

- -Drying of vegetables, fish
  - -Drying of pasta, rice
- -Heating of flour
  - -Frying of meat
- -Baking of bread, biscuits
  - -Roasting of cereals

Suggestions have been made that radiant heating elements should be operated at temperatures between 1200 and 1800°C, as only wavelengths onger than 2  $\mu m$  are effective in developing colour. Successful results have been reported for several frying applications.80

braising meat for beef stew. 81 Parboiling procedure for a similar degree of heat treatment, as compared with conventional technology, the infrared reatment required a shorter cooking time (83%) with lower weight losses (50%). The flavour, colour and texture of the infrared braised meat were Asselberg et al. used quartz tube heaters (1000–1300°C) at 2.2 W/cm² for claimed to be much superior.

oven at Swift & Company has been investigated by Hlavacek. 82 The 288 kW of infrared radiant heating from overhead quartz lamps were supplemented by electric resistance heaters below the seamless, stainless steel belt. The frying time was 2-3 min, and precooked bacon was found to An industrial process for precooking of bacon in a continuous infrared laste as good or better than freshly fried bacon.

wavelength region of 1.2  $\mu$ m. For wavelengths longer than 2.5  $\mu$ m the Several studies have been reported by Soviet investigators concerning showed that the maximum transmission of infrared radiation is for the the frying of meat with infrared radiation, but the only work published in English is that of Bolshakov et al. on the production of baked pork meat products. 83 By analysing transmittance spectrographs of lean pork they transmission was negligible. Consequently, it is necessary to use sources with the maximum radiation falling in the region of maximum transmission to achieve deep heating of pork. For heat treatment of the product surface, adiators in the region of minimum transmittance and reflectance  $(\lambda_{max} > 2.3 \, \mu m)$  must be used. The authors therefore designed a two-stage rying process. In the first stage surface heat transfer was brought about by

subjected to an infrared radiation flux with  $\lambda_{\max}$  at 1.04  $\mu m$ , providing deep and sensory quality of the products heated by the two-stage process were a radiant flux with  $\lambda_{\max}$  at 3.5-3.8  $\mu m$ . In the second stage the product was heating of the product. The result showed that the final moisture content higher than those heated by convectional methods.

### Blanching equipment

Blanching is an important process in the preservation of vegetables destined for freezing and drying. In these processes pretreatment by blanching is important for product quality and shelf life. The blanching enzymes. The time-temperature programme is outlined with the aid of transfer equations as described. In most cases heating takes place by means of steam or hot water. The heat penetration mechanism is heat transfer conduction inside the product. Due to the configuration of the vegetables the heating time is, in most cases, short or even very short. For example, the kinetic data for the enzymes of interest. These data are combined with heat from the heating medium to the surface of the product and then heat process involves short heat treatment mainly designed to inactivate natural period for peas is 1-2 min and for corn on the cob about 11 min.84

### Water blanchers

The product is transported through a hot water-bath by means of a rotary screw or a rotary drum or on a belt conveyer. One of the simplest designs is Illustrated in Fig. 5.40 showing an immersion blancher. The water is normally heated by the injection of steam. This design has certain drawbacks. With regard to the heat sensitivity of the product, rapid cooling is important. Further, energy consumption is high. Both of these factors are mproved in a design including a cooler. Water used in the cooling section is

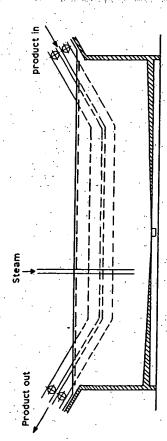


Fig. 5.40. Immersion blancher.

### Product Cross-flow of forced air evaporative cross-flow Cooling Cooling zones Cooling counter-flow Blanching cross-flow \*\*\* exchanger Heating zones Heat Product in Preheating | |

Fig. 5.41. A continuous water blancher using a cooling section.

product. In this way only a minor part of the heat treatment takes place in passed through heat exchangers used to heat the water for preheating of the hot water made up by live steam. The principle is shown in Fig. 5.41.

### Steam blanchers

Product transport through the equipment takes place in the same way as in water blanchers. Steam is injected on to the product surface and heating is rapid in the steam environment. Heating time and heat economy may be improved by means of different design features such as reduced thickness of the product, improved steam injectors, rotary valves or seals minimizing steam losses, heat recovery systems, etc. In a special design, a vibrating screw transports the vegetables inside the blancher. It is claimed that in this Spiralling or stacking in the conveyer also results in or leads to a much more compact design. In the same blancher the condensate from the heating way the products move around and heat transfer efficiency is improved. steam is used as a spray during air cooling.

### Other heating modes

For blanching of large products the heating time for the geometric centre of the product may be rather long when thermal conduction is applied as described above. Experiments have been performed to find ways

reducing this time. One way of doing this is with the aid of microwaves. In one case, referring to corn on the cob, the enzyme inactivation time was reduced to 6 min compared with 20 min when steam or hot water heating was used. Heating may also be achieved by means of an electro-conductive commercial use today. In steam blanchers the heat transfer coefficient is in The product, in this case corn, was immersed in the water but not in contact with the electrodes. In these experiments the centre temperature reached 100°C within 25-40s. None of these methods is, as far as is known, in system. Such a system, described in the literature, has electrodes in a cell filled with distilled water to which a small amount of NaCl has been added the range 1500-10000 W/m<sup>2</sup> °C.85

# EQUIPMENT FOR HEATING PACKAGED PRODUCTS

## Pasteurization and sterilization equipment

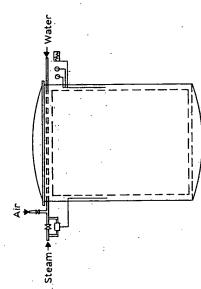
Retorts using steam for sterilization and pasteurization of food products in sans, bottles and polythene bags may be of the following types:

- -batchwise retorts, without agitation
- -rotating retorts, without agitation
- -continuous-process retorts
- -hydrostatic retorts
  - -hydrolock retorts

The first three categories are those most commonly used in the food industry.

## Batchwise retorts without agitation

the top and air is sucked out at the bottom. After heating, cooled water is often in the food industry. One advantage is the flexibility with regard to package size. Furthermore, it is relatively easy to maintain them at a constant temperature. Disadvantages are that they are laborious to operate Figure 5.42 shows the simplest type of batchwise vertical retort. It consists of a cylindrical pressure tank, into which the cans containing the food product, placed in cages, are then lowered. Steam flows into the retort from sprayed into the retort. To prevent the pressure in the cans from becoming to below 100°C the retort may be opened. This type of retort is used very higher than that in the retort itself, compressed air is blown into the retort to compensate for the pressure drop, and when the temperature is reduced



A batchwise retort without agitation. Fig. 5.42.

and that the heat transport in the product inside the packing is slow as no mixing occurs unless a product of low viscosity is processed

### Rotating batchwise retorts

batchwise retort was developed allowing for oscillation or rotation of the product. In this type of retort there is naturally a maximum speed of To shorten the sterilization time, at least when liquid food is processed, a rotation. If the speed is too high, meat cubes, for example, will be reduced to a homogenized mass. For meat products the maximum speed is about

### Continuous process retorts

Simultaneously, the can rotates around its own axis. The effect of this is a flow pattern in the package enhancing heat transport in liquids. Figure There is high pressure in the retort to prevent differences in pressure in the can and retort. The disadvantage with these retorts is the limitation on the coolers'. They are often used in large industries or canning plants. Figure 5.43(a) shows a continuous process retort with three sections; in the first section the cans are heated, in the second section the cans are cooled under nigh pressure, and in the third section they are cooled at atmospheric pressure. The cans are transported in a helix positioned on the periphery of 5.43(b) shows how the cans are transported from one zone to another. Continuous process retorts are often also called 'continuous cookera barrel, and when they have been transported one revolution of the barrel they have at the same time been moved one step along the retort.

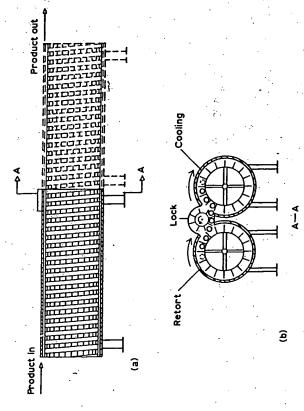


Fig. 5.43. (a) Continuous-process retort. (b) Transportation of cans from one section to another in a continuous-process retort.

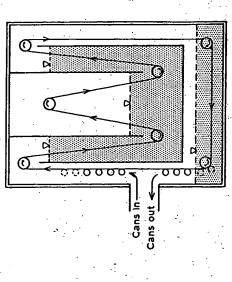


Fig. 5.44. A hydrostatic retort.

size of the cans, as they are built for one can size and only small differences in size can be accepted in the equipment.

### Hydrostatic retorts

A hydrostatic retort consists of a chamber equipped with steam injection. The chamber is connected to two water columns (barometric lock) which are used to adjust the pressure in the chamber. If the height of the water columns is changed the steam pressure is changed and thus the maximum temperature obtainable. These retorts are often very tall. To get a temperature of 116°C, a difference in height between the two water columns of 10.7 m is needed; for 121°C it is 13.7 m. A conveyer, which may be altered to accommodate different can sizes, travels through the steam chamber carrying the packages. The sterilization time may be changed by varying the speed of the conveyer. Figure 5.44 shows the principle of a hydrostatic retort. The flexibility and the capacity are the major advantages of this type of retort. The disadvantages are the size of the equipment and high capital

### Hydrolock retorts

Figure 5.45 shows how this type of equipment works. The equipment consists of a continuous retort that has a rotating pressure lock, called a hydrolock, which is partly submerged under water. The cans pass the hydrolock into a preheating chamber filled with water. They are then transported into the steam chamber. The bottom part of this chamber contains hot water thus further heating the cans. The cans are then transported to the upper part of the chamber containing steam and here sterilization takes place. The product then passes through a cooling section.

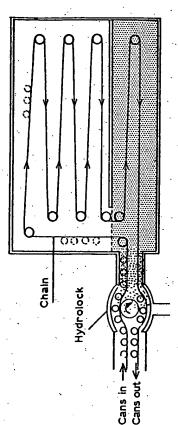


Fig. 5.45. A hydrolock retort.

Hydrolock retorts are flexible but they are rather large and costly. Leakage in the rotating valve of the hydrolock is common.

### Direct flame sterilization

Equipment for sterilization of cans transported through direct flames has contact with the cans is in the region of 1200-1400°C. The speed of rotation of the cans is high in order to avoid superheating of the can itself and thus been developed and is commercially available. The air temperature in he product.

## Models for heat transfer in cans and bags

Food products which are sterilized and pasteurized in retorts are contained in different kinds of packages. The most common is the cylindrical metal can but glass bottles and jars are also used. The package material has to be considered when calculating the heat transfer during the process. The geometry of the package also determines the geometry of the product itself. A recent development is the so-called flexible pouch made of as has been described earlier. It is, however, difficult to obtain a sharp distinction between them. There are many foodstuffs in which both a plastic material. When simulating the heat transfer the thermo-physical properties of the packaging material must be known. A liquid convectionneated food behaves differently from a conduction-heated solid foodstuff, mechanisms take place. The heat penetration during the different stages of he sterilizing process (heating, holding and cooling) is taken into account in the estimation of the microbiological destruction and nutritional losses. This is further described in Chapter 6.

Heat transfer to and from the package has been treated earlier, as has penetration inside the product will be described. Models for liquid foods that for solid food. Here some examples of theoretical models for heat and solid foods will be treated separately.

### Sterilization in cans

(a) Liquid foods. Factors that affect the heating rate of so-called convection-heated products are:55

- -container dimensions
- -viscosity of the product
- -temperature conditions
- -heating medium and heat transfer rate to the can
- —presence of solid particles

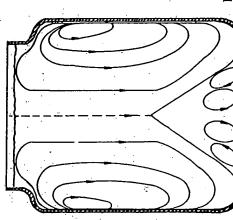


Fig. 5.46. Flow patterns during heating in a glass jar filled with water, <sup>55</sup>

Figure 5.46 shows a typical flow pattern in a glass jar filled with water, when To be able to understand the heating mechanism of liquids in a can, no forced mixing occurs. Hiddink<sup>55</sup> set up a mathematical model for temperature simulation in a non-agitated liquid being heated in a retort. knowledge of the flow patterns and the temperature profiles is required This is described earlier in this chapter (eqns (5.60) and (5.61)),

penetration in solid foods during sterilization in cans. In most cases it has been assumed that only conduction governs the heat transfer in the product. This is a reasonable assumption if effective thermal properties are (b) Solid foods. Many researchers have presented models on heat used. Lund summarizes the different models described in the literature.86

Teixeira et al.87 presented the first optimization of heat sterilization of solid foodstuffs in cylindrical cans using computer calculations. Manson et al.88 constructed a similar model for rectangular containers. The first model of Teixeira et al. does not take variable surface temperature into consideration. This was later rectified in 1975.89 The later model of Teixeira et al. will be briefly described here. The cylinder was divided into volume elements. The general differential equation for two-dimensional unsteady heat conduction in a finite cylinder is used:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial r^2} = \frac{1}{a} \frac{\partial T}{\partial t}$$
 (5.74)

ure was assumed to be uniform, and when the container was placed in the etort the wall temperature was assumed to reach the retort temperature mmediately. The cooling period was calculated by changing the wall temperature. In order to use this model the thermal diffusivity must be ogether with the finite-difference numerical method. The initial temperacnown.

immersed in a liquid, by a combination of convection and conduction. 55 (c) Liquid containing solid particles. Heat is transferred to solid objects The ratio between conduction and convection in such a product depends

- the size and shape of the solid particles
  - the arrangement of the solid elements
    - the viscosity of the liquid

<u>છ</u>

A large particle needs more time than a small one to attain a certain temperature at the centre because heat is transferred in the solid by conduction. Very little research has been done on the effect of solid particles on convection heating in liquids.

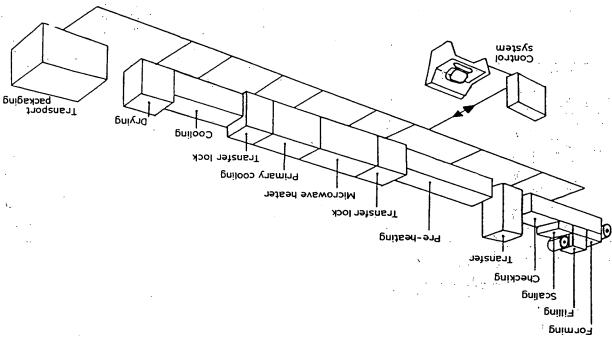
The overall heat transfer coefficient may be calculated for a container containing liquid and solids using the equation

$$= -\frac{(\rho c_p)_{bed}}{A_c} \frac{d \left( \ln \frac{I_\infty - I}{I_\infty} \right)}{dt}$$
(5.75)

a simplified model for heating liquids containing solid spheres. In this he distinguished between a boundary layer flow at the package wall, a stratified core in the upper part of the container and an eddy region in the ower part of the container. The heating of a liquid containing solid spheres different diameters of the flow-disturbing particles. Hiddink $^{55}$  constructed behaviour of the boundary layer at the wall should be considered for in which  $(c_p)_{bed}$  is the heat capacity of the container and contents. may be simulated with this model with some restrictions

### Microwave heating

his is often overemphasized. The penetration depth, which defines the 300 GHz) for sterilization. The most common frequency is 2450 MHz. One advantage of this method is a more even heating of the product although depth into the material at which the energy has decreased to 1/e of its This method is concerned with the use of microwaves (300 MHz to



Star AB, Tumba, Sweden). Fig. 5.47. The Multitherm process for microwave heating (pasteurization, sterilization) of foods in packages (courtesy of Alfa-

THERMAL PROCESSING EQUIPMENT

original value, depends on the microwave frequency and the properties of the food product. Corner and edge overheating effects often occur. One way of overcoming this is to heat the product submerged in an aqueous solution with similar dielectric properties to the product. This method has been utilized by the Alfastar Multitherm process (see Fig. 5.47).

# EQUIPMENT FOR FREEZING AND THAWING

### Freezing equipment

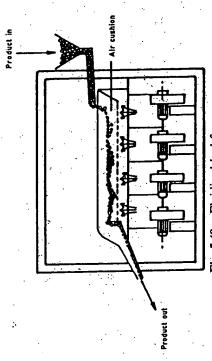
Depending on the cooling medium used, the available equipment for freezing may be grouped as follows:

- -convective (air) freezers
- -conductive (plate) freezers
- -liquid nitrogen and freon freezers

In air freezing, the air is sometimes forced (blast freezing). The velocity of the air is of importance with regard to the net heat transfer coefficient. In air freezing the low temperature is generally effected by means of a heat pump. However, to some extent nitrogen is also used. Conduction freezers are normally plate type freezers for solid food. Pellet freezers are available for liquids.

### Convective (air) freezers

This is the traditional type of freezer. In the original and simplest type the foodstuff is placed in a cooling box and surface heat transfer occurs as



7ig. 5.48. Fluidized-bed freezer.

## THERMAL PROCESSING EQUIPMENT

natural convection. This is still a common method, especially in small industries, where the food material is placed in a cold store. However, this is not a rational method as freezing is slow and other products in the store may also be affected. In blast freezing the cooled air is circulated through the freezing chamber. This chamber may be of batch type or continuous, and several designs are available. The foodstuff may be processed in the package or before packaging (IQF, Individual Quick Freezing). In a continuous freezer the product may be transported through the equipment on a trolley, a conveyer (straight or spiral screw) or in a fluid bed (see Fig. 5.48).

### Conduction freezers

Conduction freezers (also called plate freezers) were developed to improve heat transfer for regularly shaped solid food. The foodstuff is pressed between metallic plates containing channels in which the refrigerant is circulated. The design may vary in degree of sophistication. A special design for freezing liquid food into pellets is also available. The liquid is poured into small cavities in a rotating drum cooled from the inside.

### Nitrogen and freon freezers

The original direct fluid freezers used some kind of brine in which the foodstuff was immersed. Due to several reasons, mainly hygiene, this method is seldom used today. Liquid nitrogen (LN<sub>2</sub>) can be used either for immersion of the product or for spraying on to the product. Due to the low

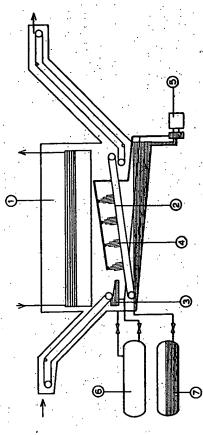
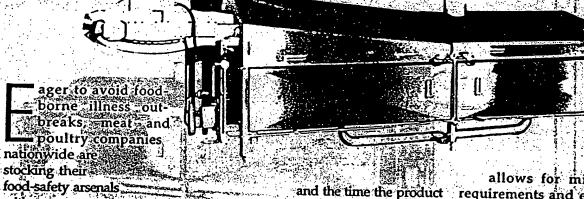


Fig. 5.49. Liquid freon freezer (LFF): 1, condenser (-43°C); 2, freezing belt; 3, IQF bath (-30°C); 4, spraying of the cooling medium; 5, circulation pump; 6, tank;

The Aquaflow pasteurization system is critical ammunition in turkey processor Plainville Farms' battle against food-borne pathogens.



is placed in a barrier bag.

What we're trying to do is repro-

duce the original pasteurization tem-

perature of one-hundred-and-sixty

degrees," explains Henley. "Our sep-

aration between cooked and raw

product is very complete, but if in the

handling of product or in the expo-

sure to the packaging area the rein-

threats throughout production. Sixth-generation turkey processor Plainville Farms, Plainville, NY, is no exception. Processing 500,000 turkeys a year for prentium all-natural deli products, Plainville in 1997 intensified its killing power against poultry-spoiling microbes with the installation of a Unithern Aquallow pasteurization system at its cooking, further-processing plant.

ζ,

Č.

engue daises d

B

with weaponry to counter microbial

The Unitherm unit is a final step to ensure that we're doing the best possible job we can to manufacture through two sparging systems, a safe product," notes Marcus Henley, plant manager.

Planothes three piece delibreis's

troduction of bacteria inadvertently occurs, this is a final safeguard." Within the Aquaflow unit, steam and water are mixed and pumped into a reservoir then introduced which agitates the water to eliminate any thermal stratification. The theat load is sufficient with the flow ate for instantaneous recovery,

eagrantil hey reached the sollowing meaning that the water continuously flows over the product's surface

The dwell time for turkey passing through the Aquaflow system is a maximum of two minutes to raise the product surface temperature to between 175°F and 180°F. A utrogen tunnel at the end of the down to less than 40°F within a maximum of 40 seconds.

tamination that could occur between Of Unitherm's Aquaflow pasteurization system's construction

allows for minimal water requirements and easy cleaning. Specifically, the tank is covered with a solid spine with flanges suitable for connection to an extraction system. Hinged lids are fitted on both sides of the spine, and a water seal at the edges prevents steam from escaping to the atmosphere.

The cooking tank is fitted for direct injection steam at a pressure of 3 bar dry saturated in a forced circulation. Sparge pumps are all stainless steel and can be used in CIP operation if necessary, and pumps have been sized to ensure maximum sparging efficiency at 550 G.P.M.

Though Plainville has not defined the Unitherm Aquaflow post-pasteurization step as a critical control point in its HACCP (Hazard Analysis and Critical Control Points) plan, Henley emphasizes that it is an indispensable part of the company's food-safety program.

"The assurances we have in operating this system make it very important to us," he says. "We have not had any issues relative to food safety since its installation. For us, I would define the post-pasteurization step as an essential process step." — Unitherm Food Systems Inc., phone (580) 762-0197, fax (580) 762-0199 CIRCLE NO. 246

are smoked or browned in according Coling the breaststate to exarded to a tackaging area where their cook in at the correct temperature. pags are stripped off before they are aguum teat sealed in barnerabaps form alkdistribution The vacuum paeked breast system his preventive step — part system chills the product back of a continuous process — is intend- down to less than 40°F, within a ed to eliminate the potential for con-

the time the cook-in bag is removed

STRUCK AND NO INCOME.

Conveyers & Press Towers

### Studies on the Application of Infrared in Food Processing.

NOTICE: This material may be protected by copyright law (Title 17 U.S. Code)

E. A. Asselbergs and W. P. Mohr Plant Research Institute, Canada Department of Agriculture, Ottawa

### J. G. Kemp

Engineering Research Service, Canada Department of Agriculture, Ottawa

INFRARED RADIATION as a source of heat has been studied for a number of applications in the food processing industry (1, 10, 11, 17). In several cases, such as the drying of macaroni (2), the roasting of coffee (7), the blanching of celery and apples prior to freezing (4) and the peeling of apples (3), infrared reportedly offered advantages as compared to other heat sources or processing techniques. These advantages differed in each particular case and varied from faster drying to improved flavor and texture. In other instances the use of infrared was not successful because of technical or economic reasons (13, 16). Shuman and Staley (16) stated that the disappointing results obtained were often due to popular misconceptions of infrared radiation, especially with respect to its penetration characteristics. These workers suggested that an evaluation of the uses of infrared should include fundamental studies on the properties of the heat source and the absorption characteristics of the produce. A survey of the available literature revealed a lack of such fundamental data. Only in the studies on the dehydration of orange juice (16) and the infrared peeling of apples (3) were the fundamentals of infrared radiation considered and related to the specific application.

In recent years, the manufacturers of infrared equipment have produced high energy content infrared radiators (1000-5000 watts) in the form of quartz lamps (9). quartz tubes (9) and calrods (14), which can be installed with greater convenience than the old bulb type lamp of low energy content (250-1000 watts). The changes in lamp design promise wider application in many industries, including the food processing industry (5, 15).

The present study was designed primarily to evaluate the three high energy, infrared radiators. The basic procedure consisted of determining the degree of heat penetration in apple tissue as effected by radiant energy produced by quartz lamps, quartz tubes and calrods. In addition, an evaluation of the following food processing applications of infrared heating is included: blanching of apples, celery and peas, the production of french fries, and the braising of stewing beef for canned stew.

<sup>a</sup> Contribution no 64, Plant Research Institute, Research Branch, Canada Department of Agriculture, Ottawa, Ontario.

### EXPERIMENTAL EQUIPMENT

The 3 types of infrared radiators used in the present study are described as follows:

a. Quartz lamp, consisting of a tungsten filament, surrounded by inert gas and suspended in a sealed, translucent, fused quartz tube.

 b. Quartz tube, consisting of a nichrome wire, surrounded by air in an unscaled, translucent, fused quartz tube.

c. Culrod, consisting of a nichrome coil surrounded by magnesium oxide insulation and sealed in stainless steel tubing.

The quartz lamp tunnel, Figure 1, used in the present study

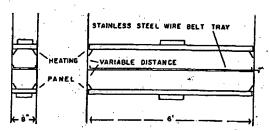


Figure 1....Plane and cross-section diagrams of the quartz lamp tunnel:

consisted of an upper and lower heating panel containing, respectively, three and two 3800 watts heating units. Each lamp was 38 in long with a 4½ in wide reflector of specular aluminum. The distance between the lamp and the produce on the stainless steel wire belt was variable from 5 to 20 in. The sides of the tunnel were left open to facilitate observation and to prevent the accumulation of heat inside the tunnel.

The quartz tube tunnel was similar in design to the quartz lamp tunnel, except that each heating unit 4 was 72 in long.

The calrod heating tunnel was similar in design to the quartz tube tunnel, except that both the upper and lower panels contained one radiant panel, each equipped with two 3000 watts heating units and anodized aluminum reflectors.

The relationship between input voltage, energy output, and spectral distribution for quartz lamps has been described by Barber (5). For instance, at an input of 650 volts instead of at the rated 550 volts, the energy output of quartz lamps increases by approximately 26% and the location of the peak wavelength is changed from 1.15 me to 1.06 me; if the input voltage is changed from 550 volts to 450 volts, the energy output is reduced by approximately 30% and the peak wavelength occurs at 1.26 mc. Similarly, the energy output of quartz tubes and calrods can be varied by over- and undervoltage operation. However, for these radiators the location of the peak wavelength is much less affected because variations in the color temperature of nichrome are more limited. The color temperature of quartz tubes can be varied only between

Presented at the Twentieth Annual Meeting, Institute of Food Technologists, San Francisco, California, May 17, 1960.

General Electric, quartz lamp, type A-105-7.

<sup>4</sup> Quartz Products Corp., quartz infra-tube.

General Electric, infrared radiant calrod panel, type OX1AA.

TABLE 1

Heat penetration into apple tissue after 5 minutes exposure to three types of infrared radiators at voltage input of 535 volts

Radiator	Energy as per thermopile	у шех	"Gorrected" e	nergy between .0 microns	Penetration	Standard error
Quarts lamp	1.86	microne 1.16 2.35 2.65	per cent 56.5 72.0 67.0	valts/cm² .77 .98 .90	mm 4.1 7.4 5.9	mm .068 .110

marized in Table 1. The data indicate that the depth of penetration corresponds closely to the amount of energy available for each radiator between wavelengths 1.4 and 5.0 mc.

From the data for quartz lamps and quartz tubes (Figure 2) it appeared that the depth of penetration decreased with increased voltage input. In Table 2 are presented the amounts of "corrected" energy required at various voltage inputs to produce 4 mm penetration into apple tissue. Results indicate that at a voltage input of 535 volts, the energy outputs required on the basis of thermopile data would be 1.35, 1.03 and 1.10 watts per cm2 for the quartz lamp, quartz tube and calrod, respectively. However, on the basis of "corrected" energy levels these figures change t .75, .75 and .74 watts per cm.2 Furthermore, the amount of "corrected" energy required from quartz lamps for 4 mm penetration decreases with increased voltage inputs. In the case of quartz tubes the amount of "corrected" energy required increases with increased voltage inputs. In other words, the efficiency of quartz lamps increases with increased voltage input and the efficiency of quartz tubes decreases with increased voltage input.

It may be noticed in the present study that the infrared absorption spectrum of apple tissue has not been considered. The infrared absorption characteristics of apple solids become important only during the advanced stages of dehydration and do not apply to experiments where short exposure times are used.

### II. Application to products

a. Blanching of celery. The harvesting season of celery in Ontario is limited to a 6-week period during September and early October. This period coincides

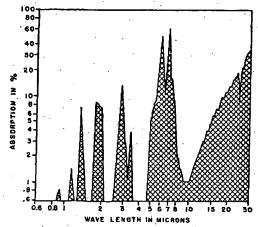


Figure 4. Absorption spectrum of water vapor (9).

TABLE 2

Effect of type of radiator and voltage input on the amount of energy required to produce 4 mm heat penetration in apple tissue

Radiator	Voltage input	λmax	Required energy as per thermopile	"Corrected" ener required between 1.4 and 5.0 micro	
	rolls	microns	watts/cm2	per cent	watts/cm2
Quarts lamp	450	1.26	1.80	62.0	.81
	635	1.16	1.85	56.5	.75
	600	1.12	1.39	58.5	.74
	660	1.06	3.46	50.0	.73
Quartz tube	535 .	2.85	1.08	72.0	.74
*	600	2.26	3.11	73.0	.81
2.00	660	2.10	1.14	75.0	.86
Calrod	535	2.65	1.10	67.0	.74

with optimum canning activity for tomatoes and therefore the production of celery soup is delayed until the winter months. However, celery cannot be stored for more than 30 days in cold storage (38° F) and in order to have a supply of celery for soup stock, the celery is frozen during the harvest season for remanufacture at a later date. If celery is not adequately blanched before freezing a bitter flavor develops during storage. The customary procedure is to trim and cut celery stalks into ½ in pieces, followed by a steam or boiling water treatment of 3 to 4 min. The product is then packed in 30 lb bags and frozen immediately.

In preliminary experiments it was noticed that the cut celery, after exposure to infrared for 3 to 6 min. would be peroxidase negative except for the outer .5 mm layer of surface tissue. The peroxidase activity in this region could be eliminated by dipping the celery in boiling water for 15 seconds prior to exposure to the infrared. The procedure adopted for. infrared blanching of celery is briefly as follows: celery stalks, free of leafy tissue, were cut in 1/2 to 6 in lengths, dipped for 15 seconds in boiling water, exposed to infrared radiation from quartz lamps for 2 to 3 min, packaged in polyethylene bags and frozen immediately. The wattage requirement from the upper and lower heating panels was approximately 1.50 watts per cm<sup>2</sup> per panel, as measured with the thermopile. Accompanying weight losses of the celery were between 25 and 35%. Load density of the fresh produce was approximately 1 lb per sq ft of belt.

After freezing and storage at 0°F for 3 and 6 months, samples of infrared and water-blanched celery were evaluated organoleptically. The infrared-blanched celery was considered superior in flavor and texture and equal in appearance as compared with the water-blanched product. One Canadian firm has used the infrared procedure on a commercial scale and in

approximately equal for the parboiled and infrared techniques.

f. Blanching of asp ragus, corn, beans, turnips and carrots. Preliminary attempts to blanch asparagus, whole kernel corn, corn-on-the-cob, cut green beans, diced turnips and diced carrots were unsuccessful. No combination of type of radiator, exposure distances and exposure period would produce sufficient heat penetration to inactivate peroxidase. In most cases the exposure to infrared resulted in surface scorching before heat penetration was more than a few millimeters.

### SUMMARY

Three types of high energy, infrared radiators—quartz lamps, quartz tubes, and calrods—were evaluated for their effectiveness in blanching apple tissue. Data are presented which show how the depth of heat penetration was influenced by wavelength characteristics, voltage input, and energy output of the radiator.

Infrared radiation was used successfully for blanching celery, apples, and peas prior to freezing and in the preparation of french fried potatoes. General quality of infrared-blanched samples was better than that of samples blanched by conventional steam or boiling water methods. Accompanying weight losses of up to 35% by weight would result in reduced freezing, storing, and handling costs in the case of products intended for later remanufacture.

Infrared was substituted for the par-boiling treatment of beef as the preliminary heat treatment in the preparation of beef stew. The colour, texture, and flavour of the infrared-braised, canned meat was considered superior to that of the par-boiled meat.

### LITERATURE CITED

 ANONYMOUS. Infrared rays in fish canning. Food Manuf., 26, 137 (1951).

- 2. Anonymous. Quick-dries with infrared. Food Eng., 27, 58 (1955).
- Asselbergs, E. A., and Powers, W. P. The peeling of apples with infrared radiation. Food Technol., 10, 297 (1956).
- Asselbergs, E. A., Mohr, W. P., Kemp, J. G., and Yatzs, A. R. Blanching of celery and apples by infrared shows flavor, texture, appearance gains. Quick Frozen Foods, 21, 45 (1959).
- BARBER, I. J. Rules of radiation. Paper presented at the National Industrial Electric Heating Conference, February 1958, Cincinnati, Ohio.
- 6. Bedford, R. E., Kemp, J. G., and Asselbergs, E. A. A cosine-corrected radiation moter for high intensity infrared. Am. Soc. Agr. Eng. Journ. (in press).
- Berard, A. Etude theorique concernant les possibilites d'utilisation des radiations infra-rouges pour la torrefaction du cafe. Inds. Aliment. et Agr., 74, 369 (1957).
- 8. CANADA, A. II. General Electric, Data Folder No. 87516 (1959).
- CHRISTENSEN, M., AND FOOTE, A. G. Development and application of quartz infrared lamps. Paper presented at the National Technical Conference of the Illuminating Engineering Society, September 12-16. 1955. Cleveland, Ohio.
- EGELER, C. E. Infrared energy in food processing. Food Packer, 29, 50 (1948).
- Ferguson, F. P. Food dehydration with infrared rays. Food in Canada, 3 (9), 17 (1943).
- Mohr, W. P., Asselbergs, E. A., and Ferguson, W. E. Studies on the application of infrared for the production of french fries. Am. Potato Journ. (in press).
- NAVELLIER, E. Utilisation des rayons ultraviolets et infrarouge dans l'industrie fruitiere. Fruits, 9, 212 (1954).
- 14. REMIZ, G. A. Calrod ovens. Design Eng., 3, 54 (1957).
- Sewin, G. L'infra-rouge et ses applications au sechage des produits agricoles et alimentaires. Inds. Aliment. et Agr., 71, 535 (1954).
- SHUMAN, C. A., AND STALEY, C. H. Drying by infrared radiation. Food Technol, 4, 481 (1950).
- TILLER, F. M., LITHENHOUS, E. E., AND TURBEVILLE, W. Infrared dehydration of meats and vegetables tested. Food Inds., 15, 77 (1943).

### COOKING METHODS FOR ELIMINATION OF Salmonella typhimurium EXPERIMENTAL SURFACE CONTAMINANT FROM RARE DRY-ROASTED BEEF ROASTS

L. C. BLANKENSHIP, C. E. DAVIS, and G. J. MAGNER

-ABSTRACT-

Three cooking procedures were tested for effectiveness in eliminating an experimental Salmonella typhimurium contaminant from surfaces of rare dry-roasted beef roasts. Dipping roasted and cooled roasts in cooking oil at 160°C (320 F) or 180°C (355°F) for a minimum, of 60 sec was effective, but submerging similar roasts contained in plastic bags in 89.4-93.3°C (193-200°F) water for 3 min was not effective in eliminating surface survivors. Injection of steam into the oven during part of the toasting period also was effective. We found that a minimum of 10 min of steam injection was necessary to eliminate the contaminant. Experiments with steam injection at the beginning or end of roasting led to the conclusion that survivors on surfaces of dry-roasted beef roasts were probably on the surface at the beginning of the roasting process. Subjective evaluation of the degree of rareness of center slices of roasts reaching maximum center temperatures between \$4.4-64.1°C (130-147.5°F) indicated the rare area decreased about 2% for each degree increase in temperature. Roast center temperatures at time of removal from the oven correlated significantly with the maximum center temperature.

### INTRODUCTION

NEW FEDERAL REGULATIONS specifying cooking procedures for commercial production of pre-cooked beef roasts were recently published (Angelotti, 1978). These procedures were designed to allow production of salmonellae-free rare beef roasts, which commercial processors had been unable to produce under previous emergency regulations. The procedures take into account the possible survival of surface contaminants during low-temperature dry roasting (Blankenship, 1978) by requiring that the relative humidity in the oven be greater than 90% for not less than 1 hr at oven temperatures below 121°C (250°F) to destroy surface contaminants. Goodfellow and Brown (1978) reported that injection of steam for 30 min into an oven at 79.4°C (175°F) was required to eliminate 10<sup>7</sup>/cm<sup>2</sup> surface salmonellae contaminants.

We tested several cooking procedures to determine if they could eliminate experimental salmonellae surface contaminants and yet produce rare roast beef. We also analyzed the relationship of (1) degree of rareness and (2) oven removal temperature to final roast center temperature.

### EXPERIMENTAL

### Roast preparation and contamination

Frozen boneless beef roasts (inside rounds) were obtained from a commercial supplier. They were thawed, trimmed, and weighed as previously described (Blankenship, 1978). Mean trimmed weight was 5.3 kg (range, 4.65-5.70 kg).

Roasts were experimentally contaminated with a strain of Salmonella typhimurium resistant to a maximum of 2000 ppm nalidixic acid. Roasts which were used for dipping in hot oil or water were contaminated by injecting  $2 \times 10^{\circ}$  cells along the geometric centerline the day before cooking as previously described (Blankenship, 1978). Roasts for steam injection roasting were each superfi-

Authors Blankenship, Davis, and Magner are with the USDA Animal Products Laboratory, Russell Research Center, SEA-AR, Athens, GA 30604.

cially contaminated in different  $5\times 8$  cm areas with  $2\times 10^7$  cells in each of the three following ways: (1) the cells (in 0.1 ml saline) were spread over the surface of the entire area with a bent glass rod; (2) the cells (in 0.1 ml saline) were injected about 1-2 mm below the surface at the center of an area; and (3) cells (in 0.2 ml saline) were injected about 1-2 mm below the surface in equal quantities at five random locations within an area. Surface contamination was performed as described, both on the day before cooking and again on different areas just prior to cooking.

Cooking procedures

Two groups of roasts were dry-roasted suspended in cotton stockinettes (nets) and cooked one or two at a time in a gas-fired pilot plant food-processing oven (Alkar Rasmussen, Alkar Engineering Corp.) at 109.4°C' (229 ± 1°F) and then removed after various periods of time, as described previously (Blankenship, 1978). Maximum center temperatures of roasts used in surface survivor experiments were 57.7-58.8°C (136-138°F). After the roasts had cooled for 2 hr at room temperature, one group of roasts in their nets were submerged in hot cooking oil (Frymax with Metsil, Proctor and Gamble, Cincinnati, Ohio) at 160°C (320°F) or 180°C (356°F) for various periods of time. The treated roasts were drained of excess oil and stored overnight in a cold room (2-4°C) before sampling for microbiological analysis. In the second procedure roasts in nets were placed in plastic bags that were evacuated to maximize contact with the bag and then submerged in a water bath at 89.4-93.3°C (193-200°F) for 3 min. The treated roasts were then stored overnight in a cold room before sampling

Roasts in another group were prepared as before and placed in the oven for steam treatment and roasting. The oven was started with the dry-bulb and wet-bulb temperature controls both wet at 82.2°C (180°F). Within 15 sec after the oven was started, steam was injected continuously into the oven for the desired time. Steam injection was stopped by setting the wet-bulb control to 4.4°C (40°F). The dry-bulb control was set at 109.5°C (229°F) for the remainder of the roasting period. Two roasts were steam-treated for the last 20 or 26 min of roasting. After removal from the oven, all steam-treated roasts were cooled for 2 hr at room temperature, then stored overnight before sampling.

Surface temperatures of the roasts were recorded from the means of 6-8 randomly located surface thermocouples that were positioned about 0.5 mm below the surface. The thermocouples were fabricated in our laboratory from 36 gauge Teflon-coated cooper-constantan thermocouple wire.

### Microbiological analyses

Core samples were taken and analyzed as previously described (Blankenship, 1978). For surface samples the inoculated 40 cm<sup>2</sup> area were excised to a depth of about 0.5 cm. Surface samples were taken before and after hot oil and water dipping and after steam treatment. Each excised sample, including cooking net, was asceptically cut into smaller pieces and macerated for 2 min in 100 ml of lactose broth with a Colworth model 400 Stomacher. Procedures for pre-enrichment, enrichment, confirmation, and determination of most probably numbers (MPN) were the same as previously described (Blankenship, 1978).

### Rareness quality analyses

Cross-sectional slices (5-8 mm thick) were cut asceptically from the center of cooked roasts just prior to microbiological sampling. The perimeter of each slice and its rare portion were traced onto matte acetate plastic film. Total and rare areas of each slice were measured with a planimeter and the value obtained were used to calculate the percentage rare portion. All tracings and judgements of rare area were performed by one of the authors. Hunter L, a, and b values were then determined for cross-sectional slices with a Hunter color and color difference meter (model D25D) equipped with an "M" optical head (2-inch diam nor)) by making adjacent, slightly

TEMPERATURE (C)

overlapping mea Statistical ar internal temper after removal f Analysis System Service (1972)

DIPPING RO
oil for 60 sec
surfaces of tv
roasts treatec
time (30 sec)
tion in one
surface conta
cm² in injec
quality of ros
mined by exx
Kermans (19
nella-free rar
in 187.8°C (
in plastic bag

Submergir plastic bags i did not elim seven roasts of surface sar

Table 1—Effect monella typhin dry-roasted bea

Treatmenta

Oil, 160°C, 5 Oil, 160°C, 60 Oil, 180°C, 60

Water<sup>c</sup>, 89.5-

a Treatments i b Frymax with

<sup>c</sup> Roasts place

### ROASTS

1 2 × 107 cells in ... n 0.1 ml saline) a bent glass rod; 1-2 mm below in 0.2 ml saline) equal quantities ntamination was oking and again

ended in cotton me in a gas-fired Alkar Engineer ved after various ip, 1978). Maxisurvivor experipasts had cooled n their nets were sil, Proctor and 0°C (356°F) for ned of excess oil ore sampling for . roasts in nets raximize contact at 89.4-93.3°C hen stored over-

re and placed in ven was stafted ols both wet at arted, steam was: ed time. Steam introl to 4.4°C (229°F) for the team-treated for om the oven, all mperature, then

aded from the uples that were thermocouples : Teflon-coated |

ously described rulated 40 cm<sup>3</sup> ce samples were and after steam net, was asceptiin in 100 ml of Procedures for termination of previously de-

ceptically from igical sampling. are traced onto each slice were I were used to l judgements of nter L, a, and b ; with a Hunter uipped with an jacent, slightly

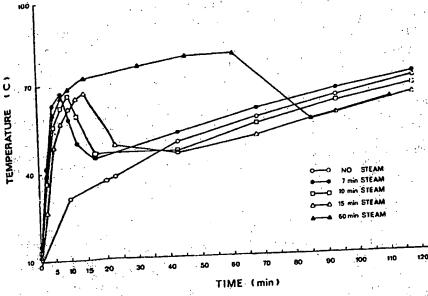


Fig. 1-Mean surface temperatures of beef roasts treated with steam during the beginning of rossting. Oven dry bulb and wet bulb settings were 82,2°C (180°F) during steam injection and 109°C (229°F) and 4.4°C (40°F) respectively, thereafter. Values are means of measurements from 6-8 surface thermocouples per roast of two roasts per treatment.

overlapping measurements to include the entire area of slices. Statistical analyses of relationships between roast weight, final

internal temperature and the continued rise of roast temperature after removal from the oven were performed with the Statistical Analysis System designed by Barr and Goodnight as described by Service (1972)-

### **RESULTS & DISCUSSION**

time (30 sec) in 160°C oil resulted in contaminant elimination in one of two roasts tested. The presence of viable surface contaminants on all roasts (mean = 1.04 ± 1.3 per cm2 in injection areas) after roasting was confirmed. Rare quality of roasts was not affected by oil treatment as determined by examination of cross-sectional slices. With a section at the section at

្នាក្រសួងនៅប្រទ**ៀ**ងការប៉ុន្តា Submerging dry roasted cooled roasts that were sealed in plastic bags in 89.4-93.3°C (193-200°F) water for 3 min did not eliminate viable surface contaminants from six of seven roasts tested (Table 1). The mean salmonellae count of surface samples taken from injection site areas before hot

Table 1-Effect of combination heat treatments on survival of Salmonella typhimurium on surfaces of experimentally contaminated. dry-roasted beef roasts

ory-rossted Deer re-	No. Salmonella positive roasts
garage and the second s	No. roasts tested
Treatmenta	1/2
Oil <sup>b</sup> , 160° C, 30 sec	0/5
Oil, 160°C, 60 sec	0/2
Oil, 180° C, 60 sec Water <sup>C</sup> , 89 5-93.3° C, 180 sec	6/7
Water, 89.5-93.5 07	the second

Treatments applied after dry-roasting and 2 hr cooling period.

b Frymax with Metsil, Proctor and Gamble, Cincinnati: Roasts placed in plastic bags and evacuated before treatments water treatment for roasts used in this experiment was 1.6 ± 2.2 per cm<sup>2</sup>.

roasts used in this experiment was surface contaminated at six 40 cm<sup>2</sup> locations with 2 × 10<sup>7</sup> S. typhimurium. Three locations were contaminated (different contamination method for each location) the day before cooking and three different locations immediately before cooking St ore Labour

frein a comment of four roasts exposed to less than 10 min initial steam treatment were positive for S. typhimurium. Steam treatment for less than the last 20 min roasting was not tested. Roast surface temperatures for various periods of intial steam injection are shown in Figure 1 as the mean temperature of 6-8 randomly located surface thermocouples for two roasts per treatment. Surface temperatures rose rapidly with steam injection compared to no steam injection, but declined rapidly when steam was terminated.

Goodfellow and Brown (1978) reported that a minimum of 30 min steam injection at the beginning or end of roasting [oven temperature 79.4°C (175°)] was required to eliminate 107 salmonellae injected just un at each of 10 sites. Our finding that 10 min or initial steam

Table 2-Effect of steam injection on survival of Salmonella typhimurium surface contaminants during dry roasting of beef roasts

murium surie	Steam injection (min)		Calculated	Salmonella detecteda
Roast no.	Initial	Terminal	R.H.	(MPN/40 cm <sup>2</sup> )
1100011101		26	63	<3
70	•		58	<3
74	•	20	78, 79, 81	<3 <3
73, 75, 76	15		78, 73, 81	<3
81, 82, 83	10		80, 83, 80	4
77	7.5		75	23
80	7		78	<3
79	7.		82	<3
79 78	5	•	74	probably numbe

a <3 means no salmonella detected in either most probably number or remainder of the macerated meat samples that were used as enrichment cultures

injection at  $82.2^{\circ}$ C ( $180^{\circ}$ F) was adequate for elimination of  $2 \times 10^{7}$  cells in each of six sites may be related to the  $109.4^{\circ}$ C ( $229^{\circ}$ F) oven temperature during the remainder of the roasting period. The newly instituted USDA regulations for roast beef require that roasts cooked in ovens at temperatures below  $121^{\circ}$ C ( $250^{\circ}$ F) be maintained at a relative humidity greater than 90% for a minimum of 1 hr during the roasting process (Angelotti, 1978). Our results indicate that shorter steam injection periods can produce salmonellae-free beef roasts and further suggest that the length of steam injection period necessary to eliminate salmonellae may possibly be related to the oven temperature used for the remainder of the cooking procedure.

We theorized in an earlier report (Blankenship, 1978) that surviving surface contaminants might occur as a result of internal contaminants being transported to the surface by meat juices after roasts were removed from the oven. An alternative explanation was that contaminants present on roast surfaces before cooking survived the roasting process as a result of surface drying (i.e. water activity reduction) that caused an increase of contaminant heat tolerance before lethal surface temperatures were reached. To clarify this question, we performed an experiment in which steam was injected at the beginning or end of roasting. Roasts used in this experiment were contaminated by injecting 2 x 107 cells per roast which were then hung in a cold room (2-4°C) overnight in the same attitude (position) as for cooking. The experimental contaminant was detected in surface samples taken from the roast sides opposite injection sites prior to cooking, which indicated that the contaminant was transported from internal locations to surface areas along natural channels. S. typhimurium was detected in surface meat samples from both the injection site area and the side opposite injection of roast No. 69 (Table 3), which was roasted without steam injection, confirming our previous finding. Steam treatment during the beginning or end of roasting eliminated contaminants from surface meat samples of both sides of the four roasts tested (Nos. 70, 74, 75, and 76) and is in agreement with the findings of Goodfellow and Brown (1978). We expected that surface survivors would be detected on roasts cooked with steam injection at the beginning of the roasting period if surface contamination resulted from transport of viable contaminants to the roast surface by cooking juices after removal from the oven. Thus, failure to detect survivors after an initial steam treatment indicates that surface contaminants surviving dry roasting likely were already on the roast surface before cooking and did not originate from leakage from internal locations.

Rare quality and assurance of salmonellae destruction were important related considerations in the development of cooking procedures and regulations for commercially roasted beef. During this study and a previous investigation (Blankenship, 1978) we examined experimentally salmonellae contaminated cooked roasts for both salmonellae destruction and rare quality in relation to maximum internal center temperature. The degree of rare quality was determined subjectively (expressed as the ratio of rare area to total area) and objectively (determined with a Hunter color and color difference meter) on center cross-sectional slices. The results of these rare quality determinations on 53 roasts cooked to maximum center temperature from 54.4-64°C (130-147.5°F) are shown in Table 4. Values were determined by least squares analysis. The higher correlations between instrument values and final internal roast temperature may be caused by the fact that color values obtained with the Hunter meter represent a mean of all observations for the entire cross-sectional area of each center slice, while the subjective analyses were a ratio between visually observed and traced rare and nonrare areas.

Table 3-Survival of a Salmonella typhimurium experimental contaminanta on surfaces of dry-roasted beef roasts treated with steam injection at the beginning or end of roasting

	•	Salmonella survival		
Roast no.	Steam treatment	Injection	Opposite side	
69	None		3106	
75	Beginning of roasting	<b>.</b>	+	
76	Beginning of roasting	-	-	
70	End of roasting		-	
74		-	-	
	End of roasting	_	~	

a Roasts were contaminated by injection of 2 X 10° S. typhimurium into geometric center areas. The contaminant was detected on injection site side and the side opposite injection prior to roasting.

Table 4-Relationship of degree of rareness and final (max) internal temperature of center cross-sectional slices from 53 beef roasts cooked to 54.4-64°C (130-147.5°F) by the dry roasting method

	Slope	Intercepta	Standard error of estimate	Correlationb coefficient (r)
Subjective (rare area/total area)	-1.99	73.04	10.95	-0.586
Hunter L value	0.26	40.80	2.642	0.373
Hunter a valued	-0.485	19.01	1.806	-0.733
Huee	0.840	29.71	3.407	0.703
Saturation	Ò.414	22.01	1.47	-0.747

- a Based on 54.4°C (130°F) origin of the X axis.
- b Critical values of significance for r: P < 0.01 = 0.345.
- c Hunter L value-sample lightness component.

投资格式器 中国制度

- d Hunter a value—sample redness component.
- e Hue-expressed by the angle whose cotangent is a/b.
- f Saturation—expressed by (a² + b²)½. Proportional to the strength of color.

Definition of the relationship between final roast temperature and the rare quality of beef roasts varies among investigators. Visser et al. (1960) described a rare roast as one cooked to a final temperature of 55°C (131°F). Griswold (1962), Bernofsky et al. (1959) and Jensen (1949) judged beef cooked to 60°C (140°F) or less to be rare. A rare roast as defined by Goodfellow and Brown (1978) is one cooked to 57°C (136°F) or below. This would correspond to a subjective area of rareness of 61% and Hunter "a" value (redness) of 16.1, hue of 34.8, and saturation value of 19.5. Our subjective data indicate that one could expect about a 2% (slope = -1.99) reduction in rare portion for each degree increase in final internal temperature between 54.4 and 64°C (130 and 147.5°F).

The extent of continued internal temperature rise after removal of roasts from the oven affects the final degree of rareness and is important to the processor, who wishes to produce a rare beef roast within the time-temperature requirements of USDA regulations. We statistically analyzed the relationship of final roast center temperature to roast weight and center temperature when removed from the oven. Sixty-four roasts ranging in weight from 4.65-5.75 kg (mean 5.4 kg) were analyzed. Oven removal temperatures ranged from 46.1-61.7°C (115-143°F). Roast weight had no effect on extent of override (r = 0.25, P < 0.05), prob ably because all roasts were trimmed to weights within a narrow range. Oven removal temperature and final center temperature were significantly correlated at the 0.04 level (r = 0.92). We derived and plotted a curvilinear (Fig. 2) equation from least squares analysis that predicts the final center temperature of a roast (y = 174.03 - 2.0865x +0.00627x2; y = degrees F override; x = roast center temperature at time of removal from the oven). Generally, removal of roasts from the oven at lower center temperatures reDEGREE OVERSUDE (F)

sulted in la center tern moval). Vi roasts cool those cook oven temp with slight

In sums surfaces all the surface cooking ju or after reduces, suc roasting or iod allow beef. Substances o between 2% reductemperatu from the mum cent

EFFECT

Kinetics line and Nordin, H.F. J. Inst. 7 Okman, W. meat pr Res. Wo Randall, C. texture texture Reith, J.E. oxide rr 82: 188

mental con-1 with steam

ı survival Opposite side

typhimuridetected on to roasting.

nax) internal beef rossn ting method

Correlationb oefficient (r)

> -0.5860.373 -0.733 0.703

> > -0.747

the strength

roast temries among are roast as 1°F). Ghissen (1949) be rare A n (1978) is ould corneand Hunter saturation one could n rare poremperature |

e rise after d degree of y wishes to perature rey analyzed re to roast n the oven. 5-5.75 kg : mperatures weight had .05), probts within 8 inal center 0.04 level ar (Fig. 2) ts the final 2.0865x + ter tempery, removal ratures re-

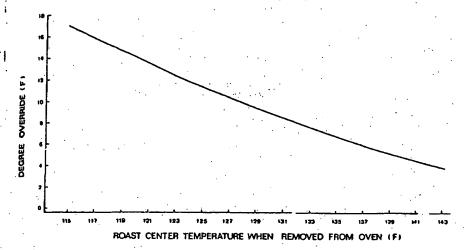


Fig. 2-Relationship of roast center tem perature when removed from oven to maximum center temperature of 64 beef roasts (4.65-5.75 kg) dry-roasted in a gas-fired pilot-plant oven at 109°C (229°F). Override is the difference between roast maximum center temperature and roast center temperature when removed from oven.

sulted in larger overrides (i.e., the difference between final center temperature and center temperature at oven removal). Visser et al. (1960) reported that the override of roasts cooked in oil at 110°C (230°F) was greater than for those cooked at 100°C (212°F). Thus, the use of different oven temperatures would likely result in override curves with slightly different characteristics.

In summary, viable salmonellae detected on beef roast surfaces after dry roasting most probably were present on the surfaces before roasting rather than being transported in cooking juices from internal locations to the surface during or after roasting. The use of combination cooking procedures, such as brief dipping in hot cooking oil after dry roasting or steam injection during part of the roasting period allowed the production of salmonellae-free rare roast beef. Subjective evaluation of the degree of center slice rareness of roasts reaching maximum center temperatures between 54.4-64.1°C (130-147.5°F) indicated about a 2% reduction of rare area for each degree of increase in temperature. Roast center temperature at time of removal from the oven was significantly correlated with the maximum center temperature.

### REFERENCES

Angelotti, R. 1978. Cooking requirements for cooked beef and roast beef, Fed. Register 43: 30791; Bernofsky, C., Fox, J.B., and Schweigert, B.S. 1959. Blochemistry of myoglobia. 7. The effect of cooking on myoglobia in beef

of myoglobin. 7. The effect of cooking on myoglobin in beef muscle. Food Res. 24: 389.

Blankenship: L.G. 1137&Surviyator a Salmonella 17phimumum experimental contaminant during cooking; of beef roasts. Appl. Environ. Microbiol. 35: 1160.

Goodfellow, S.Jy and Brown; W.L. 1978. Fate-of Salmonella incoulated into beef for cooking; of Food Protect, 41: 598. Giswold, R.M. 1962. "The Experimental Study of Foods." Houghton Mifflin Co., Boston.

Jensen, L.B. 1949. "Meat and Meat Foods." p. 147. Roland Press, New York.

New York

New York.
Service, J. 1972. "A Users Guide to the Statistical Analysis System." North Carolina State University.
Visser, R.Y., Harrison, D.L., Goertz, G.E., Bunyan, M., Skelton, M.M., and Mackintosh, D.L. 1960. The effect of degree of doneness on the tenderness and juiciness of beef cooked in the oven

and in deep fat. Food Technol. 14: 193. Weiner, P.D. and Kermans, J. 1976. Methods of prepating rare toost beet. U.S. Patent 3,961,090.

Ms received 7/4/79; revised 8/31/79; accepted 9/10/79.

The authors express appreciation to Rueh Wilson for assistance with the statistical analyses.

EFFECT OF NaCI ON RESIDUAL NITRITE . . . From page 269

Kinetics of nitrosation on the amino acids proline, hydroxypro-

Ninetics of nitrosation on the animo actus profile, hydroxypto-line and sarcosine. J. Natl. Cancer Inst. 51: 1833. Nordin, H.R. 1969. The depletion of added sodium nitrite in ham. J. Inst. Technol. Aliment. 2(2): 79. Osman, W.J. and Krol, B. 1972. The depletion of nitrite in heated meat products during storage, 18th Meeting of European Meat

Res. Workers, p. 409.
Randall, C.J. and Voisey, P.W. 1977. A method for measuring the

texture of meat and the effect of nitrite and salt addition on the texture of cured meats. J. Texture Studies 8(1): 49.

Reith, J.E. and Szakaly, M. 1967. Formation and stability of nitric oxide myoglobin. 1. Studies with model systems. J. Food Sci.

Skoog, D.A. and West, D.W. 1969. "Fundamentals of Analytical Chemistry," 2nd ed., Chi 6 and 11. Holt Rinehart and Winston, Inc.

Snedecor, G.W. and Cochran, W.G. 1978. "Statistical Methods," 6th ed., Ch. 10 and 12. The Iowa State University Press, Iowa-Ms received 7/4/79; revised 8/25/79; accepted 9/1/79.

Research supported by the College of Agricultural and Life Sciences, by the Food Research Institute and by the American Meat Institute, Muscle Biology Laboratory Manuscript # 129.

### Infrared Radiative Drying in Food Engineering: A Process Analysis

Infrared radiative drying is contrasted with conductive/convective drying. Physical and analytical aspects of the absorption of radiation by nonhomogeneous substances such as foodstuffs are discussed. Transport processes in infrared heating are evaluated considering industrial conditions at which infrared drying is feasible.

Constantine Sandu, Department of Food Science, University of Wisconsin-Madison, Madison, Wisconsin 53706

### Intr duction

When incident upon a physical body, the radiation in the wavelength range 0.10-100 µm generates heat. The spectrum of thermal radiation is mostly covered by infrared radiation. Conventionally, the specific limits of the infrared spectrum are: near infrared (0.75-3.00 µm), middle infrared (3.00-25 µm) and far infrared (25-100 µm).

Industrial radiative heating relies mostly upon infrared radiators which have their spectral distribution with the peak (the wavelength at which maximum flux is emitted) situated in the near and the beginning of middle infrared. Based on wavelength, infrared radiators are divided into light radiators (working in near infrared) and dark radiators. Quartz glass radiators have a spectral peak at 1.2 µm, ceramic radiators at 3.1 µm and metal radiators at 2.7-4.3

A comparison between convective and radiative heating reveals the high efficiency of the radiation heat transfer [1]; convective heating with air at 250°C can realize heat fluxes of about 0.9 to 2.0 kwatts/m², whereas radiative heating produces heat fluxes of about 4.5 to 12.0 kwatts/m² with dark radiators and 4.5 to 25.0 kwatts/m² with light radiators. The particular properties of infrared radiation, i.e., high intensities of incident radiation fluxes (20 to 100% more than in conductive heating [2, 3]) and the possibility of precisely controlling the incident radiation fluxes, open new possibilities for technical processes using radiation.

Great attention has been paid in the last decades to development of new physical methods for treating food products, particularly the electromagnetic methods which include the utilization of the infrared radiation. Although the economic aspects are still controversial, the available data give some assurances of the profitability of infrared heating in food engineering [2-8].

Infrared heating can be used in baking, roasting, thermal treatments (blanching, pasteurization, smoking tes) and drying of foodstuffs. In this review, the focus will be primarily on the interaction between infrared radiation and foodstuffs with most attention on radiative drying.

The main parameters characterizing the equipment of convective/conductive drying have been estimated based on data available in the literature (Table 1). When applied

to drying of foodstuffs, the specific drying capacity of this equipment is close to the lower limit of the indicated ranges. This is because the drying temperature has to be maintained at levels where the thermal degradation of products is minimized.

Data in Table 2 describing radiative drying of some food products have been adapted from Déribéré [18]. The equipment used to dry these products is of both the batch and continuous-belt type involving continuous or intermittent irradiation. The performance of this particular radiative drying equipment competes successfully with that of the convective tunnel dryer (see Tables 1 and 2).

The process economy of infrared radiative drying of foodstuffs has the potential to be further improved by implementing adequate process/equipment design concepts. Nevertheless, for foodstuffs, product quality and process economy can not always be judged on a common basis. Depending upon the product, the location, and the circumstances, a comparatively poor quality product may be acceptable if the costs are low enough, or a high quality product may be desired even though the costs of obtaining it are high [19].

### **Extinction of Radiation**

The mechanisms responsible for attenuation of electromagnetic radiation as it propagates through a medium are absorption and scattering. Converting the radiation to some other forms of energy (or some other spectral distribution) is called absorption phenomena, whereas scattering mechanisms are those which redirect the radiant energy from its original direction of propagation due to a combined effect of reflection, refraction and diffraction. The sum of the mechanisms of attenuation of electromagnetic radiation as it passes through a medium (absorption plus scattering) is generally called extinction of radiation (see Figure 1).

When the extinguishing material is agglomerated into particles, separated by regions of different transmissivities (such as emulsions and dispersions), or when variations occur in the density of the sample (as in capillary-porous bodies or in bodies subject to a temperature or moisture gradient, or in solid bodies which contain a liquid, free

TABLE 2. RADIATIVE DRYING F FOOD PRODUCTS

product	Specific Drying Capacity kg ev.wat./m²/hr	Characteristic Dimension of Drying Product (thickness)	Drying Time hr	Heat Consumption kJ/kg ev.wat.
shelled green beans <sup>1)</sup>	2.46	10 mm	2.16	5280
green beans shelled	2.40	10 11111	2.20	0200
geen peas1)	4.26	10 mm	2.50	3040
sliced				7.
carrots1)	2.96	5 mm	3	4370
sliced				,
turnips1)	3.88	6 mm	2	3340
shredded				•
cabbage"	3.52	10 mm	1.5	3680
tomatoes2)	1.25	halves	12.5	7140
diced				
pumpkin <sup>2)</sup>	1.07	8-10 mm	7	8410
sliced	· · · · · · · · · · · · · · · · · · ·	··.		
aubergines	1.23	7-8 mm	4	7310
diced				4.54
potatoes1)	<b>3.33</b>	5 mm	2	5400
	4.44	10 mm	3	4050
	4.44	20 mm	6	4050
plums	4.11	whole	3	3150
apricots	4.11	halves	3.5	3150
peach s	4.11	halves	. 4	2950
sliced				03.40
apples	2.05	10 mm	. <b>4</b>	6140
sliced		10		5010
pears	2.19	10 mm	4.5	5910
sliced	. 0.05	10 mm	6	6290
quinces flour <sup>1,3)</sup>	2.05	10 mm 4 mm	3-4 min	6290 6660-8460
caseine <sup>1,4)</sup>	3.63-6.77	4 mm 20 mm	3-4 min	2540
caseme	6 6.54	20 mm 50 mm	ა 5.5	2300
sardines <sup>1,3)</sup>	9.09	whole	3.5 10-12 min	7850

1) radiators with spectral peak at about 1.2 µm

2) programmed intermittent irradiation

3) continuous belt dryer

4) using agitation each quarter of an hour

Data adapted from Déribéré [18].

teractions due to the chemical bonds characterizing the given biochemical molecule itself, and in the second group there are the well-known hydrogen bonds (as important forms of interactions with the extramolecular environment). Some simple hydrogen-bond systems in biochemistry under the influence of infrared radiation were studied by Liddel [31].

The wavelength region of interest in discussing the interaction of radiation with foodstuffs can be restricted to the infrared range 0.75 to 15 µm. Even for high temperature radiators, the spectral heat flux [(watts/m²)/µm] as-

cribed to wavelengths larger than 15 µm represents a small fraction of the total radiative power.

Due to a lack of sufficient information, data on absorption of infrared radiation by the principle food constituents must be regarded as approximate values. Amino acids, proteins and nucleic acids reveal two strong absorption bands localized at 3-4 μm and 6-9 μm [32, 33]. Figure 2 gives the infrared absorption spectra of gelatin and egg albumin [18]. Lipids are strong absorbers over the entire of infrared radiation spectrum with three stronger absorption bands situated at 3-4 μm, 6 μm and 9-10 μm [34, 35].

The absorption bands of water vapors are centered at 1.14, 1.38, 1.87, 2.7 and 6.3 µm for 0°C. These values are from Jamies n et al. [47] and Sparrow et al. [48] and are confirmed by many other papers. The first three absorption bands of water vapors are weak so that water vapor has two principal absorption bands occurring at 2.7 and 6.3 µm.

A correlation of absorption data by water vapors at temperatures from 300°K to 1100°K, taking into account the influence of mass of vapors per unit area, pressure and temperature, has been reported by Eduards et al. [49].

The effect of other gases on absorption of infrared radiation by water vapors as a function of the partial pressure of the gases was studied by Vasilevskii [50]. The effect of air seems to be negligible, and generally the air is considered as a non-participating gas in radiation absorption [48].

The absorption bands of liquid water are centered at 1.19, 1.43, 1.94, 2.93, 4.72, 6.10 and 15.3 µm at 25°C [51]. The four principal absorption bands of liquid water are 3, 4.7, 6 and 15.3 µm (see Figure 4). The absorption band at 15.3 µm actually extends over the range 10-40 µm. Temperature has no significant effect upon these absorption bands [52-54].

The effect of film thickness on absorptivity of water is given in Table 3a [55, 56]. These data show that liquid water tends to be totally absorbing even at small thickness when irradiated with monochromatic light at the principal absorption wavelengths.

But, in an industrial heating application, physical bodics are not irradiated with monochromatic sources of light. Figure 5 gives the total transmissivity of water films when exposed to the radiative heat flux of a radiator with a spectral peak at about 1.2 µm. In this case, the depth of penetration for water is about 3 mm.

A particle placed in a beam of radiant energy will both absorb and scatter the incident radiation [27]. The extent of the extinction process is determined by the complex refractive index of the material as well as the dimensionless Mie parameter  $\alpha = 2\pi r/\lambda$ , where r is the radius of the particle [m] and  $\lambda$  is the wavelength [m] of the incident radiation [27-29]. Figure 6 gives the extinction area coef-

FIGURE 5. Total transmissivity of water to the radiative heat flux of a radiator with spectral peak at about 1.2µm. Adapted from Déribéré [18].

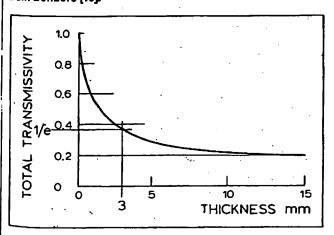
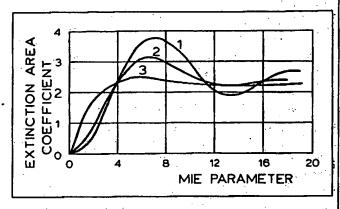


FIGURE 6. Extinction area co fficient of water particl s Irradiated with radiation f 2.2 µm (curve 1), 2.95 µm (curve 3) and 7.7 µm (curve 2). Adapted from Johnson and Terrell [57].



ficient of water particles [57]. As the radius of the particle increases, the extinction process tends to be complete, that is, the extinction area coefficient tends asymptotically to the value two. In Table 3b, the absorption area coefficient of water particles is given from data of Irvine and Pollack [58], at the principal absorption wavelengths of liquid water.

The principal absorption bands of solid water are located at about the same wavelengths as for liquid water [59]. Studies of the absorption spectra of ice films are par-

TABLE 3. ABSORPTION OF INFRARED BY WATER
FILMS AND PARTICLES

		wavelength µm					
Thickness of film µm	3.0	4.7	6.0	15.3			
1.2	0.800	0.040	0.300	<u>.</u>			
3.0	0.970	0.100	0.550	'			
10.0	1.000	0.350	1.000	1.000			
a. spectral di	rectional a	bsorptivity	•				

wavelength	μm	
•		

Diameter of particle µm	3.0	4.7	6.0	15.3
2.0 6.0 20.0	1.116 1.279 1.130	0.065 0.262 0.677	0.312 0.857 1.219	0.214 0.585 1.151
h absorption	area coeffi	cient		

Data adapted from Plyler et al. [55;56] and Irvine and Pollack [58].

FIGURE 9. Infrared absorption spectra of dry apples (1), apple with 86.6% moisture (2), potat es with 74.5% moisture (3), dry potatoes (4), potat starch with 76.5% moistur (5), p tato starch with 11.8% moisture (6), dry tea leaves (7), and fresh tea leaves (8). Adapted from Il'iasov and Krasnikov [70].

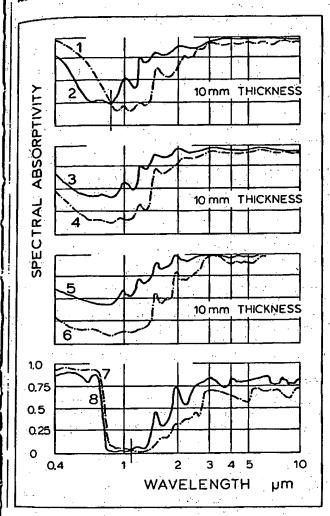
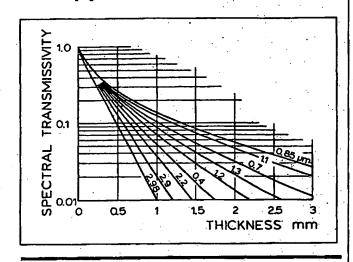


FIGURE 10. Spectral transmissivity of potato starch with 11.8% m isture at different wavelengths. Adapted fr m Il'iasov and Krasnikov [70].



### **Radiative Drying**

As a unit operation, radiative drying of capillary-porous and colloidal bodies originates with the classical theories of Lykow [71]. Related aspects to the mechanism of radiative drying are treated by several authors [2, 18, 70, 72]. Déribéré [18] and Ginzburg [2, 3] concentrate on infrared radiative drying of foodstuffs. Principles in designing tunnel-type radiative dryers are outlined by Filonenko and Lebedew [73] and Il'iasov and Krasnikov [70].

Assume a solid plate, at room temperature, is suddenly exposed to a radiative heat flux incident upon one of its faces, whereas the opposite surface is adiabatically insulated (see Figure 11). Consider also that the absorbed radiation is completely attenuated within a certain depth, the depth of attenuation. The superficial layer corresponding to this depth may be considered a location of an almost uniform heat-generation. This can be expected when the incident irradiance is polychromatic (industrial infrared radiators) and the body has an involved infrared absorption spectrum (foodstuffs). At surface 1, the plate will lose

TABLE 4. TOTAL TRANSMISSIVITY OF FOODSTUFFS TO THE RADIATIVE HEAT FLUX OF LIGHT RADIATORS

0.6 -0.7	
0.12-0.18	•
0.05	
0.558	
0.914	
0.950	
	0.914

diation (thin slabs and films; particles; dispersions; sprays), (b) intermittent irradiation of the product according to a calculated time sequence and (c) combined heating/drying nethods which involve the use of radiation, convection

and conduction.

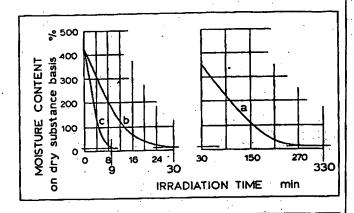
The method of intermittent irradiation was suggested by Lykow [71]. This can be done by exposing the surfaces of the body to the radiation at defined time intervals or by continuous agitation of the particular products, and by programming the radiative flux so that periods of irradiation alternate with periods of relaxation for the moisture. The radiative heat flux can be programmed in terms of inlensity, spectral peak and operation time. Radiative heating is sufficiently versatile to allow such operation. Based upon the infrared properties of foodstuffs and especially upon their behavior during infrared drying (how infrared absorption changes versus moisture-content decrease), the intensity and the spectral peak of the radiative heat flux are specified accordingly. The duration of pauses is directly connected with how fast the moisture transfer takes place within the drying body. The apparent advantages of intermittent irradiation are: energy savings; shorter drying times at low temperature of the product; easy accommodation with convective, conductive and vacuum drying methods.

Specific energy consumption in drying apples under various conditions is given by Ginzburg [2] (Table 6). The adiative flux was either constant during the whole drying process or its was programmed in time at different intensities (without pauses). The distribution of the radiative flux was done so that the product received more energy in the initial stages of drying when the moisture was higher. Three zonal irradiation resulted in about 38% energy sav-

ings compared with constant irradiation.

In the experiments of Lykow [71] (Figure 13), drying potatoes to the same final moisture content required the following irradiation times for different methods: 330 minutes (continuous irradiation), 30 minutes (1:20 intermittent irradiation) and nine minutes (1:40 intermittent irradiation). The energy savings in the 1:40 intermittent irradia-

FIGURE 13. Int rmittent irradiation applied to drying of potatoes: (a) constant radiation, 330 minutes; (b) intermittent radiation, 2 second irradiation and 40 second pause; (c) Intermittent radiation, 2 second irradiation and 80 second pause. Adapted from Lykow [71]



tion was almost 97% compared to continuous irradiation. In addition, at the end of the drying process, the product temperature was 28°C in the intermittent method versus 75-80°C in the continuous one [71].

In terms of combined heating/drying methods, all known types of drying equipment (tunnel, spray, pneumatic, drum, belt, fluidized-bed, foam-mat, rotatingthin-film, freeze, microwave, vacuum driers) can use infrared heating to supplement or to reduce energy consumption. The entire problem becomes one of process analysis and optimization.

A combined method such as infrared heating of a convective fluidized-bed was able to achieve high drying rates in thick layers of grain (100 to 300 mm) with good

TABLE 6. SPECIFIC ENERGY CONSUMPTION IN DRYING OF APPLES UNDER VARIOUS CONDITIONS

1.41
A-TA
1.40
1.01
•
·
0.87

### Literature Cited

- Minhorst, S.; Industric-Anzeiger Nr. 100. Ausgabe 'Warme- und Kältetechnik, Heizungs- Lüftungs- und Klimaanlage," Helt 6 (1970). Ginzburg A. S.; Application of Infra-red Radiation in Food Processing; London (1969).
- Ginzburg, A. S.; Infrarottechnik und Lebensmittelproduktion; Leipzig
- (1973). Ginzburg, A. S., V. V. Krasnikov; Infrared Radiation as a Method of Technological Processes Intensification in Food Industry, Paper at the and Int. Cong. Food Sci. and Techn. (1966).
- Co. C. Y. C. L., G. E. Livingston, Food Techn., 23, 1568 (1969). Kamovnikov, B. G., E. I. Kaukhtcheshvili, N. A. Prishedko, E. T. Yaushova, E. I. Guigo, L. S. Malkov; The Use of High Temperature Radiation Energy. Supply for Freeze-Drying under Industrial Conditions; Paper at the 2nd Int. Cong. Food Sci. and Techn. (1966). Hammond, L. H., Food Techn., 21, 735 (1967).
- Lisiecki, W., J. M. Plaksin, A. S. Ginzburg; Przeglad Pickarski i Cukierniczi, 21, 139 (1973).
- Schiefer, K. (ed.); Lexikon der Verfahrenstechnik; Stuttgart (1970). Schonnüller, J.; Die Erhaltung der Lebensmittel; Stuttgart (1966).
- Brennan, J. G., J. R. Butters, N. D. Cowell, A. E. V. Lilly, Food Engineering Operations; London (1976).
- R Hall, C. W., A. W. Farrall, A. L. Rippen; Encyclopedia of Food Engineering: Westport, Connecticut (1971).
- 13 Heimann, W.: Grundzüge der Lebensmittelchemie: Darmstadt (1976).
- H. Perry, R. H., C. H. Chilton, S. D. Kirkpatrick (ed): Chemical Engineer's
- Handbook: New York (1963).
- 15 Kjergard, O. G. Effects of Latest Developments on Design and Practice of Spray Drying. In: Spicer, A. (ed.); Advances in Preconcentration and Dehydration of Foods; London (1974).
- 16. Anonymous; Anhydro Zerstäubungs-Trocknungsanlagen; Bulletin 1592, Anhydro A/S, Kopenhagen
- 17. Anonymous; Escher Wyss Typenliste Walzentrockner. Escher Wyss TR 36415.
- Déribéré, M.; Les Applications Pratiques des Rayons Infrarouges; Paris (1954).
- 19 King, C. J. Novel Dehydration Techniques. In: Spicer, A. (ed.); Advances in Preconcentration and Dehydration of Foods; London (1974).

- vances in Preconcentration and Dehydration of Foods; London (1974).
  20. Jones, R. N.; J. Amer. Chem. Soc., 74, 2681 (1952).
  21. Henry, R. L.; J. Opt. Soc. Am., 38, 775 (1948).
  22. Pfund, A. H.; Plays. Rev., 36, 71 (1930).
  23. Lejeunc, R., G. Duyckaerts; Spectrochemica Acta, 6, 194 (1954).
  24. Duyckaerts, G.; Spectrochemica Acta, 7, 32 (1955).
  25. Bonhomme, J.; Spectrochemica Acta, 7, 32 (1955).
  26. Otvos, J. W., H. Stone, W. R. Harp; Spectrochemica Acta, 9, 148 (1957).
  27. Van der Hulst, H. C.; Light Scattering by Small Particles; New York
- (1957)28. Sandu, C., W. E. L. Spiess, W. Wolf, I. Rasenescu; A Survey of Theoreti-
- cal Fundamentals to Radiative Drying of Sprays and of Falling Clouds; BFE-Bericht 1976/I, Bundesforschungsanstalt für Ernährung, Karlsruhe.
- 29. Sandu, C., W. Wolf, W. E. L. Spiess, I. Hascnescu; Lebensm.-Wiss. u. Technol., 9, 321 (1976).
- 30. Halford, R. S.; Annals of the New York Academy of Sciences, 69, 63
- Liddel, U.; Annals of the New York Academy of Sciences, 69, 71 (1957).
- Koegel, R. J., R. A. McCallum, J. P. Greenstein, M. Winitz, S. M. Bimbaum, Annals of the New York Academy of Sciences, 69, 94 (1957).
- Blout, E. R.; Annals of the New York Academy of Sciences, 69, 84 Schwarz, H. P., L. Dreisbach, R. Childs, S. V. Mastrangelo; Annals of
- the New York Academy of Sciences, 69, 116 (1957).
  Freeman, N. K.; Annals of the New York Academy of Sciences; 69, 131
- Szymanski, H. A.; Interpreted Infrared Spectra; 2; New York (1966).
- Manning, J. J.; Appl. Spectrosc., 10, 85 (1956). Goulden, J. D. S., J. W. White; Nature, 181, 266 (1958).
- 39. Sternglanz, H.; Appl. Spectrosc., 10, 77 (1956).

- Polo, S. R., M. K. Witson; J. Chem. Phys., 23, 2376 (1955).
- Kalman, O. F., J. C. Decius; J. Chem. Phys., 35, 1919 (1961).
- 42. Bakhshiev, N. G., O. P. Cirin, V. S. Libov; Opt. Spectrosc., 14, 255
- 43. Bakhshiev, N. G., O. P. Girin, V. S. Libov; Opt. Spectrosc., 14, 336
- 44. Bakhshiev, N. G., O. P. Girin, V. S. Libov; Opt. Spectrosc., 14, 395
- 45. Iogansen, A. V., E. V. Broun, G. D. Litovchenko; Opt. Spectrosc., 18, 18 (1965).
- Iogansen, A. V., E. V. Broun; Opt. Spectrosc., 23, 492 (1967).
- Jamieson, J. A., R. H. McFec, G. N. Plass, R. H. Grube, R. G. Richards; Infrared Physics and Engineering, New York (1963).
- Sparrow, E. M., R. D. Cess; Radiation Heat Transfer; California (1970).
- Edwards, D. K., B. J. Flomes, L. K. Glassen, W. Sun; Appl. Opt., 4, 715. (1965).
- Vasilevskii, K. R.; Opt. Spectrosc., 11, 109 (1961).
- Zolotarev, V. M., B. A. Mikhailov, L. I. Alperovich, S. I. Popov; Opt. Spectrosc., 27, 430 (1969).
- Fox, J. J., A. E. Martin; Proc. Roy. Soc., 174, 234 (1940).
- Ciguère, P. A., K. M. Harvey; Can. J. Chem., 34, 798 (1965).
- Oder, R. D. A. I. Goring; Spectrochemica Acta, 27, 2149 (1971).
- Plyler, E. K., N. Acquista; J. Opt. Soc. Am. 44, 505 (1954).
- Plyler, E. K., N. Griff; Appl. Opt., 4, 1663 (1965). Johnson, J. C., J. R. Terrell; J. Opt. Soc. Am., 45, 451 (1955).
- 58. Irvine, W. M., J. B. Pollack; Icarus, 8, 324 (1968)
- Zolotaryov, V. M.; Opt. Spectrosc., 29, 599 (1970).
- Lucchesi, P. J., W. A. Glasson, J. Am. Chem. Soc., 78, 1347 (1956).
- Brink, G.; Spectrochemica Acta, 28, 1151 (1972). Low, M. J. D., R. T. Yang, Spectrochemica Acta, 29, 1761 (1973).
- 63. Bonner, O. D., C. F. Jumper, Infr. Physics, 13, 233 (1973).
- Luk, W. A. P., W. Ditter, J. Phys. Chem., 74, 3687 (1970). Senior, W. A., R. E. Verrall; J. Phys. Chem., 73, 4242 (1969).
- 66. Brink, G., M. Falk; Spectrochemica Actu, 27, 1811 (1971).
- Pimentel, G. C., A. L. McClellan; The Hydrogen Bond; San Francisco
- Avramenko, V. N., M. P. Esel'son and A. A. Zaika; (Infrared Spectra of Food Products); Moscow (1974).
- Mohsenin, N. N.; Electromagnetic Radiation Properties of Foods and Agricultural Products; New York (1984). Piasov, S. G. and V. V. Krasnikov; (Fundamental Principles of Infrared
- Radiation of Food Products); Moscow (1978).
- Lykow, A. W.; Experimentelle und theoretische Grundlagen der Trocknung; Berlin (1955)
- 72. Brügel, W.; Physik und Technik der Ultrarotstrahlung; Hannover (1951).
- Filonenko, G. K. and P. D. Lebedew; Einführung in die Trockentechnik; Leipzig (1960).
- Luikov, A. V.; Heat and Mass Transfer in Capillary-porous Bodies; Oxford (1966).
- Sandu, C.; Kombinierte Konvektions- und Strahlungs-Anlage für mehrstufige Vakuum-Verdamfung. Patentanmeldung P2849862.6, Deutsches Patentamt, München, 1978.

Constantine Sandu graduated as an Engineer from the University of Calatz, Romania. He was a plant engineer in the canning industry and then taught and did research in the Department of Food Engineering at the University of Galatz. Following this with research and development work at the Federal Research Center for Nutrition in Karlsruhe, West Germany, and the Society for Industrial Heating and Engineering Ltd. in Krefeld, West Germany. Presently, he is a Ph.D. candidate at the University of Wisconsin-Madison majoring in Food Engineering and minoring in Chemical and Mechanical Engineering. His main areas of research are equipment/process development and design, and process control.

is a system ith such a and learn the cook. educed, as and dis-

horizontal conclusions anizational

the flow

th vertichain f blish the smooth the flow inization. is built and effi-

al move, the layte where ad wher likely to

involved in Obserwill not onal conition and provides iorizontal

ntil others
Too often
ne actual
d at the
nation.

principal
e human
, Human
nd Action
ther pubi for Inion, Man

NOTICE: This material may be protected by copyright law (Title 17 U.S. Code)

### The A.G.S. Food System— Chilled Pasteurized Food

Col. Ambrose T. McGuckian, U.S.A., Ret. President, A.G.S. Food System, Inc.

"Develop a better system of hospital food service, better especially from the patient's standpoint and better economically" was the objective I received from Arthur W. Dana, internationally known food consultant with whom I was associated as project manager during a regional food study which extended from mid-February to mid-October 1968.

The study was sponsored by the Duke Endowment and three South Carolina Hospitals—Anderson, Greenville and Spartanburg—in whose honor the resulting system was named. Carl Rowland of the Duke Endowment had suggested to administrators of three hospitals seeking a more effective food system that regionally processed refrigerated foods might be worthy of investigation. The Cryovac Division of W. R. Grace Company also participated in the project—a participation vital to its success. Cryovac's contribution included high, low and automated vacuum equipment, water bath cookers,

packaging material and Charles Ready, packaging engineer and food technologist.

The "climate" for the study was extraordinarily good. The Piedmont Region of the Carolinas is dynamic and progressive. At every level, management is looking for better ways to do things. Advantage was taken of the favorable climate and a Working Committee was formed. In addition to the Project Director, William Cain, the project manager, Mr. Ready, the food technologist and George Kraft (an Associate of Arthur Dana), the Working Committee consisted of Clen Pottz, microbiologist, Greenville; Mrs. Virginia Fowler, ADA, chief dietitian, Greenville; Miss Mattie Mae Reavis, ADA, food service director, Anderson; Dan Phillips, food service director, Spartanburg, and Mrs. Marcelle Scoggin, ADA dietitian, Greenville. All gave full measure of their professional competence. Their counsel and objective criticism were extremely helpful in evolving the AGS method of institutional food service. - A. T. McG.

DEVELOPING A BETTER SYSTEM of hospital food service required, first of all, a target for quality. Next, an analysis of traditional methods of preparing food on a meal basis, noting advantages and disadvantages. The same procedure needed to be followed with frozen and other convenience food systems, observing advantages and limitations. By maximizing advantages and minimizing disadvantages of the traditional and the convenience food systems, it might be possible to evolve a better food service system — our purpose.

Epitomizing the advantages of the traditional system of meal preparation is the skilled housewife who, with her kitchen adjacent to her dining room, takes pride in presenting every item of each

meal to her family at its peak of temperature, flavor and succulence. Such food should satisfy the most critical patient and would have high therapeutic value. Getting food to the patient at its peak of quality and temperature became our primary target.

Traditional methods of hospital food service have locked operations into a spiral of ever-increasing costs in food, wages, equipment and supplies without any noticeable improvement in quality standards. Dedicated dietary staffs are engaged in a daily struggle to provide patients with acceptable meals meeting minimum temperature requirements. Sometimes they win and are encouraged by the compliments received. Just as

alarly, the

10ds were heir possinomic adof frozen d of qualiel, equipproduction vings were aced conperations. ty is good. ods were: nel of disality; food nenu varioods were astes; and ime, labor

ither than is concept is types of tion is less siques are acture and

dling and s in their s refrigeraduct long regionally ssed food achieving

food servtrolled retives were

for speould be ords the b procse of as ocedures ti n.

1. Quarterly

Capture and retain the aroma, flavor and fresh taste of food to the point of consumption by the patient.

 Completely inhibit the growth of any harmful bacteria from time of processing to time of consumption.

4. Have a shelf life of at least sixty days.

Improve nutritional qualities at point of consumption over traditionally prepared foods.

6. Assure patients and staff hot, satisfying meals.

Basic to the achievement of the aforementioned objectives was the requirement that quality control measures be rigorously followed from development of ingredient specifications, to preparation, processing, storing, distributing, reheating and final delivery to the patient.

### **Developmental Stage**

In our initial processing, fully cooked food prepared by the regular cooks was vacuum-packaged, pasteurized, chilled and held at low refrigerated temperatures for a period of thirty days. Of twelve processed items randomly chosen and taste tested by the Working Committee test panel, two were considered very acceptable and ten were rated barely satisfactory. "Tired food" best describes the taste panel's reaction to food fully cooked before processing.

Although somewhat discouraged by the taste panel's unfavorable reaction, an analysis of the problem indicated a solution to me. This was to stop packaging and processing fully cooked food. Instead, complete the cooking in the pouch after it had been vacuum sealed, thereby capturing and retaining the flavor of food at its peak of excellence. Thus evolved the A. G. S. System.

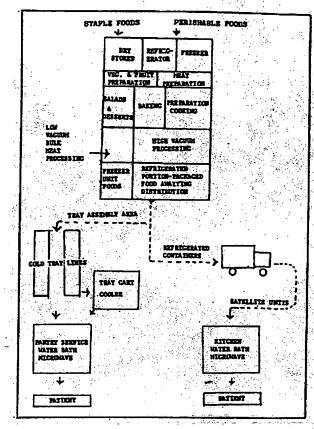
Several preparation and processing techniques were developed. Depending on the food item itself, it would be portioned in one to five portions and vacuum-packaged while at various degrees of doneness, this means prior to being fully cooked as with a stewed type item such as meat or chicken pot-pie, or when partially cooked, such as fried chicken. Grilled items, such as chopped sirloin steak, are placed on a grill just long enough to set and give surface color. Some foods are placed in the package raw and completely cooked within the pouch in a temperature-controlled water bath.

### A. G. S. Processing System

A description of the A. G. S. Processing System follows:

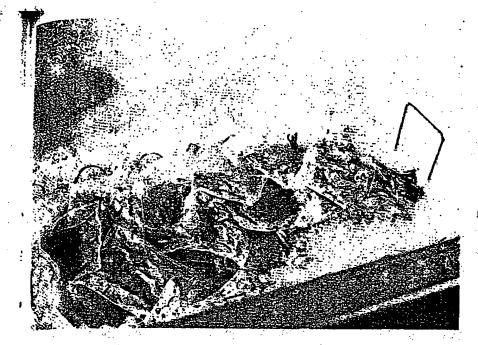
May 1969

### A. G. S. FOOD FLOW CHART



- 1. The ingredients for a particular recipe are assembled either raw or partially cooked as prescribed, portioned, packaged under vacuum, then pasteurized and cooked for a specified time in a thermostatically controlled water bath.
- 2. The prepared product is quick chilled in an ice water tank, then stored in a walk-in refrigerator especially modified to hold at 28°F to 32°F, the lowest holding temperature range possible to hold food without freezing. These procedures inhibit the growth of any harmful bacteria and permit a proven shelf life of at least sixty days, a major criteria for the new system.
- 3. Distribution of the refrigerated food to using satellite facilities outside the Greenville General Hospital is presently by means of covered plastic containers with the product surrounded by crushed ice. These food containers are transported in the delivery vehicle of the receiving hospital.
- 4. Upon receipt at the William G. Sirrine Hospital, the pilot testing facility for patient acceptability, food items for the approaching lunch on meal are placed in their sealed

Continued



Left
Fig. 3 — C mpletely process d food pouches are quick-chilled before being placed on wire racks and carted to the walk-in refrigerator.



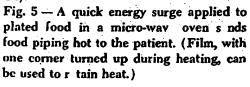
Right

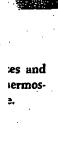
Fig. 4—Interior view of the especially modified refrigerator which holds food within a temperature range of 28°F to 32°F and does not freeze the food. For distributing chilled food to satellite hospitals, the completed system plans to use a mobile refrigerator unitized container holding up to 1200 portions, similar to the Freez-Porter insulated mobile refrigerator.





Left





s f r several

many ovens vens, parts? ises in event

ible of heatriod and, in essary. Meded in servics as in teleens in event

nvert to the

ninimum by sonv ntional were purms of labor kitchen peo-

s system to hospital, or to meet the

Hill-Burton whether the is, and state e have not cirements, I e to lack of yould be re-

olved in the ice or conid off-hour

to convert ce feedingilled sande price den products ovens durr meal can pouch pack How many new hospital and nursing home operations do you have in the planning stage? How will they differ from Tucson?

At present, we have food systems for four major h spitals in the planning stage. Two of these are conversions, two are being planned for new buildings. Both of the new installations are high-rise buildings. One will have pantry refrigerators on each floor sufficient to hold all three meals at once so that kitchen preparation will be handled in one eight-hour shift. In the other, we will utilize automated, refrigerated carts to deliver chilled food to the floors for microwave heating.

What do you consider the major advantages of systems using convenience foods?

As mentioned, food controls are better. Most of the food supply is under direct control of the dietitian. There is little instance of run-outs from inadequate food estimating or waste from over-estimating. If too much food is defrosted, it can be held safely in chilled state for serving the next day.

The savings in labor is perhaps the most attractive aspect of convenience systems. Skilled cooks and bakers — which are increasingly difficult to obtain — are almost unnecessary. Unskilled new hires can be trained on premises as food handlers. Under ideal refrigeration conditions, three meals can be prepared in a single shift by food handlers under dietetic supervision. With centralized tray assembly, there is less demand on the time and energy of the dietary staff. Food handlers operate the service pantries, including microwave operation and tray distribution.

Ronald P. Kooser was graduated from the School of Hotel Administration at Cornell University in 1961, with a concentration of courses in Food Facilities Engineering. Since graduation, h has been employed by Stouffer's, first in the company's Management Food Service Division in Philadelphia, and presently at corporate head-quarters in Cleveland.

AGS, continued from page 92.

quieter operation. From management's point of view, much more time and attention can be given to patient care and to more orderly planning.

The Greenville Hospital System saw so many advantages for continuing and developing the system further that it appointed a Director of Commissary Operations upon conclusion of the study and will expand the present pilot operation to include other satellite units. Construction of a Regional Commissary is being considered. In plans for a 200-bed unit to be set up on the A. G. S. System, which will also supply an additional 330 beds in the satellite units, an annual savings of \$92,000 is indicated. Savings are substantial in space, conventional equipment and production personnel.

The greatest possible savings appear to be possible through the establishment of regional commissaries, either through cooperative joint venture

agreements or on a contract basis with a private corporation with distribution to using facilities by temperature controlled containers such as the Freeze Porter System.

While this article has emphasized the application of the A. G. S. System to hospitals, it is equally applicable to other mass feeding media such as schools, colleges, military bases, institutions and hotels and restaurants. It is especially advantageous to institutions with multi-unit food service facilities. One production center can supply the full cooked food requirements of the institution effecting tremendous savings in personnel, food, equipment and space while satisfying th customer better than ever done before.

Thus, the A. G. S. System is a better system. It offers a fresh new approach to mass feeding techniques which with nurturing and development may well revolutionize institutional food preparation.

proteins. August 1980, CFTRI, Mysore 1981, 230, zit. b. 153. — 48. So uth D. J. und F. G. Lowman: in: Radiobiological survey of Rongetap and Allinginae Atolls, Marshall Islands, October-November 1955, Univ. of Washington, U.S. A.E.C. report UWFD-43 1955, S. 65. — 49. Strom. P. D., J. L. Mackin, D. M. c Donald und P. E. Zigman: Longlived cobalt isotopes observed in fallout. Science 128 (1962), 417. — 50. Taylor, D. M.: Physics in Med. and Biol. 6 (1962), 445 zit. nach Henning, A. u. M. Anke: Der Mineralstoffwechsel in: Hock, A (80), S. 542. — 51. We gorek, W., K. Głogowski und E. Czaplicki: Possibility of contamination of insectivorous game birds during ecological investigations using insects labeled with "Co. Nucl. Sci. Abstr. 21/3 (1967), 691. — 52. Weiss, H. V. und W. H. Shipman: Biological concentration by killer calms of "Co from radioactive fallout. Science 125 (1957), 695. — 53. Weißbecker, L.: Kobalt ats Spurenelement

#### The microbiological shelf life of vacuum packed broiled chickens

R. W. A. W. Mulder and A. R. Gerrits

Speldernoit institute for poultry research, processing department, Beekbergen, the Netherlands

#### Introduction

Vacuum packed broiled chickens with a barbecue flavour have recently been marketed in Holland and Germany.

There is no information available on packaging, storage temperature and stability, microflora and other criteria, however.

Most literature relating to barbecue products comes from research workers in the USA.

But the products described are not comparable to the product at present manufactured in Holland.

Preparation and composition of the US barbecue products are different and there is no vacuum packaging. They are not sold in supermarkets but in cafetarias and the like (S e n n & WIII i a m s , 1967). For these reasons the majority of workers describe the public health aspects of barbecue products with reference to the presence of Salmonellae.

Pivnick et al (1968) described the growth of microorganisms causing various forms of food infection and food poisoning (Staphylococcus aureus, Salmonella typhimurium and Clostridium perfringens) in barbecue chickens. The latter proved to be an excellent nutrient medium for the growth of these microorganisms.

Although there are few points of comparison between American barbecue products and the Dutch vacuum packed broiled chickens with a barbecue flavour these articles nevertheless point up the difficulties that may be encountered in ensuring the shelf life of this product.

But from a public health point of view the presence of Salmonellae is not so important as the presence of some Clostridia strains in the vacuum packed broiled product.

The shelf life of a precooked chicken product was described by Logan et al (1951), also the effect of hot and cold packaging of the product on the bacteriological quality was studied. Hot packaged products were found to have a far better bacteriological quality.

Vacuum packed broiled chickens, however, were not reported in literature. The main benifits of vacuum packing are that it prevents the product from drying out during storage and that it increases the shelf life by preventing the growth of psychrophilic bacteria which cause putrefaction (Roth&Clark, 1972).

Although vacuum packing is known to retard the growth of putrefying bacteria, little is known about the microbiology of vacuum packed broiled chickens with a barbecue flavour.

Pierson et al (1970) and Reagan et al (1971) indicate which microorganisms can survive vacuum packing, but scarcely any information is available on the factors involved. In any case there are no data on the minimum amount of

oxygen needed for the growth of putrefying and other groups of unwanted bacteria.

Table 1 gives some data on oxygen requirements of bacteria (I n g r a m, 1962).

Table 1: Oxygen partial pressures needed for the growth and respiration of various microorganisms (ingram, 1962)

	growth	p0 <sub>2</sub> (atm) respiration	temp. (° C)
Clostridium tyrobutyricum	0.003		37
Lactobacillus pastorianus	0.02	0.01	25
Escherichia coli	0.01	•	37
		0.01	25
Acetobacter	0.005-0.004	0.03	25
certain yeasts		0.01	27
,		0.001	16
		0.0004	5

As can be seen there are not much data available, and also there is scarcely no information on the micro-ecological conditions in the vacuum packed broiled chickens, as a result of the changes in the composition of gas during storage, although it is known that oxygen is used for the growth and respiration of the microorganisms present, CO<sub>2</sub> being released.

In the present investigation an attempt was made to measure the growth of various microorganisms, or rather various groups of microorganisms, when the packaged samples were stored at given temperature. In this way it was possible to estimate the shelf life of the vacuum packed broiled chickens with a barbecue flavour.

With a view to extending shell life, influenced by post-contamination of the uppacked product the brolled chickens, which were already vacuum packed, were surface pasterrised in hot water.

#### Material and methods

#### Starting material

Soft-scalded chickens were used as starting material for the preparation of the brolled chickens. After cooling these chickens were rinsed with chlorinated water, cured in brille, and given the specific tayer of aroma for a barbecue flavour.

The chickens were broiled, the oven temperature rising to about 200° C. After cooling they were cut in helves and vacuum packed. The oxygen permeability if the packaging material, a polyethylene nyl in, was 0.9 x 10<sup>-9</sup> cm²/O₂/cm²sec cm Hg.

#### Pasteurization treatm nt

The pasteurization treatment was carried out as follows in a cooking vat (Haas und Sohn):

Table 2: Microbiological determinations on the starting material

	PCA 33 TOP MISS	VRBG	·:-%	ECA/#		OGGA	OLSON
Starting material m.o./g after curing in brine after broiling after cooling	6.8.10 <sup>4</sup> 2.5.10 <sup>5</sup> < 100, 4.5.18 <sup>2</sup>	8.4.10 <sup>a</sup> 2.2.10 <sup>a</sup> < 10 < 10		1.0.10° 6.3.10° < 100 < 100	1.3.10⁴ 4.7.10⁴ < 100 < 100	7.4.10 <sup>3</sup> 5.2.10 <sup>3</sup> 1.0.10 <sup>2</sup> < 100	8.2.10 <sup>3</sup> 2.2.10 <sup>4</sup> 1.0.10 <sup>3</sup>

- a. The vacuum packed product was heated for 20 minutes in water of 70° C ( $\pm$  1° C) and them cooled for 15 minutes in water of 11° C ( $\pm$  1° C).
- b. The vacuum packed product was heated for 20 minutes in water of 80° C (± 1° C) and then cooled for 15 minutes in water of 11° C (± 1° C).

#### Storage conditions

The storage stability tests were applied to the pasteurized and unpasteurized product at:

- a. 1 (± 1)°C
- b. 5 (± 1)° C
- c. 20 (± 1)° C.

#### Microbiological examinations

The skin crush method described by Veerkamp et al (1972) was used for homogenizing the samples of meat and skin.

Two vacuum-packed chicken halves were examined weekly.

Three samples of meat and skin were taken from each chicken-half and homogenized.

#### Media

The	following	media: were	used	for	the	microbiological
	nination:		• •	,		•

Plate count agar (Oxoid) total aero- bic bacterial count	48h 30° C PCA
Violet red bile glucose agar (Oxold)  Enterobacteriaceae	18-24h 37° C VRBG
Enterococci confirmatory agar (Dif- co) faecal streptococci	48h 37° C ECA
Mannitol salt agar (Oxoid) micro-	401 050 0 504

Oxytetracycline yeast glucose agar (M o s s e I et al, 1962)

(Mosseletal, 1962) Yeast and moulds

cocci

Olson agar — Psychrophilic microorganisms

Clostridium pertringens was detected on Reinforced Clostridial Medium (Oxoid).

48h 37° C ECA

48h 22° C OGGA

120h 12° C

#### Microbiological criterion for shelf life

In order to evaluate the results, and to predict shelf life, a limit was set for bacterial count. This limit was based on the statutory requirements regarding pasteurized products.

As a rule, the total bacterial count in this type of product may not exced 50 000 per gram.

This is only intended as an indication that difficulties might be encountered if pathogenic bacteria are in the product, it does not give information about wholesomeness of the product.

#### Results and discussion

The results f th microbiological determinations n the starting material are presented in Table 2.

The shelf life is determined by the total number of bacteria present, subdivided into (about) five groups f microorganisms.

Counts less than 10 and less than 10<sup>2</sup> indicate the limit of accuracy f the method of determination empl yed.

Table 3: Changes in psychrophilic microorganisms in barbecue chickens stored at a low temperature

days at 4-6° C	Olson medium	days at 0-2° C	Oison medium
n	< 100	0	< 100
5	5.0.10°	5	7.0.103
14	2.0.103	14	7.0.10
20	1.0.105	20	1.0.10
26	2.4.104	26	1.0.104

Figures 1 and 2 show the total count and the *Enterobacte-riaceae* count in brolled chickens as a function of the storage time.

It can be seen (Fig. 1) that after 3, 9 à 10, 20 à 21 days the specified limit of 5.0.10° microorganisms per gram is exceeded in broiled chickens stored at + 20° C, + 5° C and + 1° C respectively.

The Enterobacteriaceae in Figure 2 show distinct growth at +5° C and +1° C after a 5-day storage period.

Before this period the number of microorganisms to be determined was less than 10 per gram.

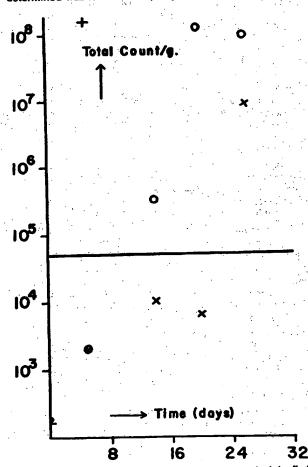


Figure 1: Microbiological shell lile of vacuum-packed brolled chickens. Total count

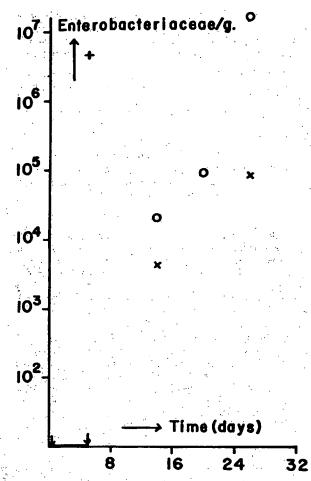


Figure 2: Microbiological shelf life of vacuum-packed broiled chickens. Enterobacteriaceae count

For yeasts and moulds there is an increase after a 5-days period at  $+5^{\circ}$  C. At  $+1^{\circ}$  C scarcely any growth was detected throughout a 26-day storage period.

The counts of psychrophilic microorganisms are given in Table 3. No growth was detected of the faecal Streptococci, Micrococci and Staphylococci or of Clostridium perfringens.

On the 26th day only 1.2.10 faecal Streptococci per gram

In the unpasteurized product a distinct growth of Enterobacteriaceae was found. Since the Salmoneliae, known to be a public health hazard, belong to the Enterobacteriaceae, two investigations were done on the pasteurization of the vacuum packed broiled chickens in order to suppress growth of these microorganisms.

No Clostridia were detected in this product so the Salmonellae were of more importance to look for.

Table 4: Growth of psychrophilic microorganisms after pesteurization at 80°C during the storage of barbecue chickens

days at 0°-2° C	•	Olson medium	
0	. *	< 100	
5		1.0.103	
14	•	< 100	
35	100	< 100	
41 .		5.0.101	
47		8.0.104	
55		1.0.105	

Figures 3 and 4 show the total counts in chickens pasteurized at  $70^{\circ}$  C and  $80^{\circ}$  C. It was found that the spoilage limit is about 31 days for chick ns pasteurized at  $70^{\circ}$  C and at red at  $+5^{\circ}$  C, and at least 31 days at  $+1^{\circ}$  C.

Pasteurizati n at 80° C gave the same number of days.

The high ounts after 3 days are caused by favourable conditions, before the vacuum packaging is effective on the growth and viability of the microorganisms. It was noticeable that no *Enterobacteriaceae* counts higher than 10 per gram were determined at either pasteurization temperature when the chickens were stored for 54 days at +5°C and +1°C.

Spoilage was due to psychrophilic microorganisms surviving these pasteurization temperatures.

An exchange of the growth of these microorganisms is given in Table 4.

Of the other media employed, growth occured in the yeasts and moulds only. No yeasts or moulds were detected after pasteurization at 70° C and 80° C and storage at 4°-6° C. On the other hand, after a storage period of 54 days at 0°-2° C, 1.8.10° m.o/g were detected in barbecue chickens pasteurized at 70° C and 1.0.10° m.o/g in those pasteurized at 80° C.

The results obtained make clear that barbecue chickens have a limited shelf life I. e. a maximum of 21 days under ideal storage conditions when the total bacterialcount is not allowed to exceed 5.0.104 m.o/g. But the total bacterialcount is not the only criterion needed for assessing the product. This is shown by the pasteurization tests, in which

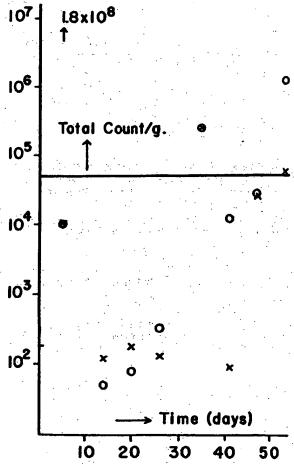


Figure 3: Microbiological shell life of vacuum-packed pasteurized (70° C) brolled chickens

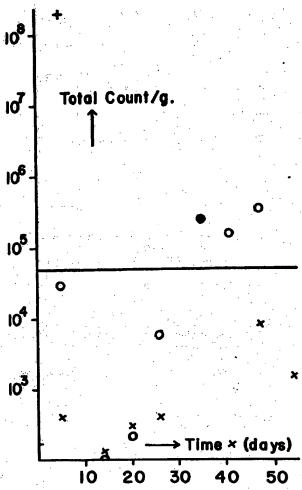


Figure 4: Microbiological shelf life of vacuum-packed pasteurized (80° C) broiled chickens

in the figures:

+ stored at + 20° C

O stored at + 5° C

× stored at + 1° C

the shelf life is in any case 31 days. Whereas the absence of pasteurization permits the growth of Enterobacteriaceae yeasts and moulds, only psychrophilic microorganisms were able to develop in the pasteurized product.

The Enterobacteriaceae, including the Salmonellae were so inhibited by pasteurization, that no growth of this group of bacteria was beerved when the total count was already as high as 104 microorganisms per gram. Under these conditi ns the psychr phili fi ra (and to a lower extent th y asts and moulds) sh wed t be a more important factor.

Although no Clostridia were d tected in this investigations, th risk of a Clostridia-infection is still present under practical conditions.

The present investigation points up however the many factors which have effect on the shelf life of vacuum packed barbecue chickens.

#### Acknowledgements

The authors wish to thank Mrs. M. C. van der Hulst and Miss E. I. Cornelissen de Beer for their skilful assistance with the microbiological examinations.

#### Summary

The microbiological shelf life of vacuum packed broiled chickens with a barbecue flavour was estimated. Also the extended shelf life after a pasteurization treatment was investigated. Barbecue chickens, vacuum packed, have a limited shelf life, i. e. a maximum of 21 days under ideal storage conditions. After a pasteurization treatment this is

#### Zusammenfassung

Mikrobiologische Haltbarkeit von vakuum-verpackten gebratenen Hähnchen mit "Barbecue" (Holzkohlenrost)-Geschmack wurde untersucht. Außerdem wurde die verlängerte Haltbarkeit nach einer Pasteurisierung geprüft. "Barbecue"-Hähnchen, die vakuumverpackt sind, haben beschränkte Haltbarkeit, und zwar ein Maximum von 21 Tagen unter idealen Lagerungsbedingungen. Nach einer Pasteurisierung wird diese Haltbarkeit auf 31 Tage verlängert.

Ingram, M. (1982): Microbiological principles in pre-packing meats. J. Appl. Bact. 25, 259.— Logan, P. P., C. H. Harpaw. F. Dove (1951): Keeping quality of precooked frozen chicken a laking, a bacteriological evaluation of hot and cold packs. Food Technol. 5, 193. — Mossel, D. A. A., M. Visser & W. H. J. Mengerink (1962): A comparison of media for the enumeration of moulds and yeasts in toods and beverages. Lab. Pract. 11, 109. — Pierson, M. D., D. L. Collins - Thompson & Z. J. Ordal (1970): Microbiological, sensory and pigment changes of serobically and anaerobically packaged best. Food Technol. 24, 129. — Pivnick, H., J. E. Erdman, S. Manzatiuk & E. P. Pommier (1968): Growth of food poisoning bacteria on barbecued chicken. J. Milk and Food Technol. 31, 198. — Reagan, J. O., L. E. Jeremiah, G. E. Smith & Z. L. Carpenter (1971): Vacuum packaging of lamb. 1. Microbial considerations. J. Fd. Sci. 38, 764. — Roth, L. A. & D. S. Ciark (1972): Studies on the bacterial flora of vacuum-packaged fresh beef. Can. J. Microbiol. 18, 1761. — Senn, C. L. & P. A. Williams (1987): Public health aspects of robiseries in markets. J. Milk and Food Technol. 39, 116. — Veerkamp, C. H., R. W. A. W. Mulder & A. R. Gerrits (1972): Kühlung und Reinigung von Schlachtgeflügel. Fleischwirtschaft, 52, 612.

#### Ein Verfahren zur Bestimmung der Sauerstoffdurchlässigkeit von Wursthüllen

Von M. Schaal, R. Bach und H. Rüter

Aus dem Institut für Hygiene und Technologie des Fleisches im Department Tierärztliche Lebensmittelwissenschaft der Tierärztlichen Hochschule Hannover - Direktor: Prof. Dr. S. Wenzel

#### **Einleitung**

Neben mikrobiellen und physikalischen Ursachen stellen chemische Veränderungen ein häufig Verderbnisquelle für alle Wurstarten und -sorten dar. Das Ranzigwerden des Wurstfettes dürfte die vorherrschende chemische V rd rbnis sein, als deren katalytische Faktoren vor allem Sauerstoff, Licht und Wärme in Frage kommen. Während di Licht- und Wärmezufuhr weitgehend durch die Art der Lagerung zu regulieren sind, kann der Zutritt von Sau rstoff zum Wurstgut nur über die Hülle beeinflußt w rden.

Deshalb erschlen es uns wichtig, eine Möglichkeit zu schaffen, die verschiedensten Wursthüllen - einschließlich der Naturdärme - vergleichend auf ihre Sauerstoffdurchlässigkeit zu prüfen.

#### Schrifttum

Die im Schrifttum ang führten Versuchsanordnungen zur Messung der Permeabilität von Kunststoffmembranen ermöglichen durchweg gut reproduzierbare Ergebnisse (Müll rund H uwink, 1954; Henn ssy et al., 1967; Gaudig, 1969; DIN 53 380; Nõsel, 1969, 1972a u. Journal of Food Protection, Vol. 49, No. 1, Pages 42-46 (January 1986) Copyright<sup>®</sup> International Association of Milk, Food, and Environmental Santarians

NQTICE: This material may be protected by copyright law (Title 17 U.S. Code)

ina Vu. Ma Sist mil

ma: S

icir. 1 ; pen

trea 18

the 2. 5

beir wer

H bac:

cm-

meti

san:

appi

(Dif

of c

sam

40 c

rem:

pool

WETE

with

of s

for !

follo

(a)

4) p

Enu:

(Oxc

tero:

at 😳

tres::

Ino.:

7955

the r

wash

7.00

ban:

less :

at 46

mo:"

in :-

pu-

בונת

iar..

WZ.

gren:

In:

and

## Microbiological Stability of Pasteurized Ham Subjected to a Secondary Treatment in Retort Pouches

P. J. DELAQUIS, R. BAKER and A. R. McCURDY

Department of Applied Microbiology and Food Science, University of Saskatchewan, Saskatchewan S7N 0W0, Canada

(Received for publication May 17, 1985)

#### ABSTRACT

A ham processing procedure consisting of pasteurizing, packaging in retort pouches, and subjecting the hams to a secondary heat treatment was evaluated as a method of increasing microbial stability. Pasteurized hams reheated at 121°C for 10 min and stored at 1±1°C or 6±1°C showed no microbial growth after 6 or 12 months of storage. The number of microorganisms in pasteurized hams not receiving the secondary heat treatment ranged from  $10^3/g$  to  $>10^8/g$  and from  $10^2$  to  $>10^8/cm^2$  on the surface after 3 to 5 months of storage. Pasteurized hams that had been inoculated with Clostridium sporogenes spores before pasteurization followed by a secondary heat treatment at 121°C for 10 min showed a delay in the occurrence of swollen packages when stored at room temperature compared to hams not receiving the secondary heat treatment. However, the secondary heat treatment did not prevent spoilage of hams. Ham that has not been treated to eliminate spores should be refrigerated.

Pasteurized canned hams are classified as semi-preserved meat products (2). The expected shelf life of these products is from 3 to 6 months under refrigeration (11,12). They range in size from small 454-g cans designed for the retail market to 11.3-kg hams for the wholesale trade.

The pasteurization process ensures destruction of most vegetative cells in ham with the exception of heat-resistant strains of Streptococcus faecalis, S. faecium, Micrococcus sp. (8) and Lactobacillus viridescens (13). Spores of both Clostridium and Bacillus survive the heat treatments commonly employed with such products and can germinate and grow out to cause spoilage (9.15). It is because f the potential survival of these spoilage and pathogenic organisms that pasteurized ham is refrigerated.

The constantly rising cost of metal cans has led the meat industry to consider the retort pouch as an alternative packaging system. At present the cost of a retort pouch suitable for the packaging f an 11.3-kg ham is roughly one fourth of that for a metal container. Pouches

also occupy much less space in storage and are much more easily disposed of by the consumer or retailer.

Because retort pouches lack the rigidity of metal cans and hence the ability to impart shape during processing, we have investigated a process consisting in three stages:
(a) pasteurization in a stainless steel mold, (b) subsequent vacuum packaging in a retort pouch, and (c) high temperature short-time processing of the product to eliminate contaminating organisms acquired on the surface of the ham during handling between stages (a) and (b)

According to a patent issued to Kueck et al. in 1965 (10), a process similar to this leads to shelf stability of canned ham. Although it is generally accepted that such suboptimal heat treatments cannot ensure the safety of cured meat products at room temperature, we have investigated the possiblity that our process leads to shelf stability.

The following experiments were designed to determine whether our high-temperature short-time process is effective in eliminating contaminants on the surface of retort-pouched hams to yield a shelf-life equivalent to that expected for a conventional pasteurized canned ham.

#### MATERIALS AND METHODS

Storage experiments

Ham preparation. The storage experiments were done using a commercial ham formulation: boned hams were pumped to 114% (by weight) with brine to obtain a final salt concentration of 3% and 150 ppm sodium nitrite. The raw harn pieces were tumbled in a KSI ham massager (Knud Simonsen Industries, Toronto, Ont.) continuously for 24 h and subsequently pumped into dual chambered molds (11.4×11.4×91.4 cm, Mepaco, Oakland, California) that had been fitted with polypropylene liners (Teepak-Non shrink, Toronto, Ont). Each mold received approximately 10 kg of raw ham. The molds were processed in a still retort at 76°C until an interal temperature of 71°C was reached (about 4.5 h). The temperature was monitored by means of two 5-cm thermocouples (OF Ecklund, Cape Coral, Florida) using a Honeywell model 111 recorder (Fort Washington, Pennsylvania). Following pasteurization, hams were chilled overnight at 5°C.

Present address: Intercontinental Puckers Ltd., P.O. Box 550, Suskatoon, Suskatchewan S7K 3U4

President, SIDNEY BARNARD, 9 Bortand Lab, Pennsylvania State University, University Park, PA 16802.

President-Elect, ROY GINN, Dairy Quality Centrol Inst., 2353 No. Rice St., Room 110, St. Paul, MN 55113.

Vice-President, LEON TOWNSEND, Milk Control Branch, Bureau for Health Services, 275 East Main St., Frenkfort, KY 40601.

Secretary, ROBERT GRAVANI, 8A Stocking Hall, Cornell University, Ithaca, NY 14853. Past-President, ARCHIE C. HOLLIDAY, VA Dept. of Ag., 1100 Bank St., Room 511, Richmond, VA 23219. 3=

The 028

P

Foc

PO

He.

5.

**5**:

Par.

801

E¢t:

Sage

5370

5001

Men scr

Inst

Die e

Orde

be s

5001

able

to or

Bus.

DBS.E

S:::

Harre

Subs

ume

000-61

Volum

Un.

M 45

Suiz

\$3:::

æ · :

**ab.** :-

41.55

232-65

Memb

S 4.4

£5: . .

to \*\* #

D4 = .

Sha. i

a.:-

**s** :.

Cia.

recons.

Ai 🔑

ancic...

70: -

N:

Affiliate Council Chrpn., HELENE UHLMAN, 1532 W. 4th Place, Hobart, IN 46342.

#### Editorial Board

J. C. ACTON, SC (88)
W. H. ANDREWS, DC (86)
R. W. BENNETT, DC (86)
L. C. BLANKENSHIP, GA (86)
L. B. BLCHANAN, PA (85)
L. B. BUCHANAN, PA (85)
J. G. CERVENY, WI (86)
F. M. CLYDESDALE, MA (87)
D. COLLINS-THOMPSON, Onl. (88)
R. CORDS, MN (88)
N. A. COX, GA (88)
P. M. DAVIDSON, TN (86)
J. Y. D'AOUST, Onl. (88)
G. B. DENNY, DC (87)
R. W. DEXERSON, Jr. OM (87)

R. S. FLOWERS, IL (87) P. M. FOEGEDING, NC (87) J. F. FRANK, GA (88) J. T. FRUIN, HI (86) C. P. GERBA, AZ (88) B. A. GLATZ, IA (87) C. R. HACKNEY, LA (87) W. M. HAGLER, Jr., NC (86) P. A. HARTMAN, IA (68) W. J. HAUSLER, Jr., IA (88) D. L. HUFFMAN, AL (88) J. M. JAY, MI (88) J. A. KOBURGER, FL (88) P. E. KOEHLER, GA (88) A. A. KRAFT, IA (87) D. H. KROPF, KS (87) E. P. KRYSINSKI, CA (96)

R. LABBE, MA (87) B. E. LANGLOIS, KY (87) R. A. LEDFORD, NY (88) J. LISTON, WA (87) J. M. MADDEN, DC (86) R. T. MARSHALL, MO (88) S. E. MARTIN, IL (87) D. W. MATHER, IL (87) T. J. MONTVILLE, NJ (87) J. H. NELSON, IL (88) S. A. PALUMBO, PA (87) J. J. PESTKA, MI (88) M. D. PIERSON, VA (87) B. RAY, WY (87) R. B. READ, Jr., DC (87) G. H. RICHARDSON, UT (MI) J. R. ROSENAU, MA (67)

D. A. SCHIEMANN, MT (87) P. M. SCOTT, Onl. (86) D. B. SHAH, OH (88) G. A. SOMICUTI, PA (87) W. H. SPERBER, MN (87) W. M. SPIRA, MD (87) D. F. SPLITTSTOESSER, NY (87) N. J. STERN, MD (88) M. E. STILES, AD., (SE) H. E. SWAISGOOD, NC (87) N. TANAKA, WI (96) S. L. TAYLOR, WI (86) R. M. TWEDT, OH (88) N. UNKLESBAY, MO (87) C. VANDERZANT, TX (88) J. H. VON ELBE, WI (87) D. C. WESTHOFF, MD (88) V. L. ZEHREN, WI (87)

#### **IAMFES Sustaining Members**

Alta-Laval, Iric. Agri-Group 11100 North Congress Avenue Kansas City, MO 64153

M. W. EKLUND, WA (87)

G. FINNE, TX (87)

Aipha Chemical Services, Inc. P.O. Box 431 Stoughton, MA 02072

Anderson Chemical Co. Box 1041 Litchfield, MN 55355

Angenics, Inc. 100 Inman St. Cambridge, MA 02139

Associated Milk Producers, Inc. 830 N. Meacham Rd. Schaumburg, IL 60195

Babson Bros. Co. 2100 S. York Road Oak Brook, Illinois 60521

Borden, Inc. Dairy & Services Div. 16855 Northchase Houston, TX 77060

Dairymen, Inc. 10140 Linn Station Road Louisville, KY 40223

Darigold 635 Elliott Ave. W. Seattle, WA 98109

Dean Foods 1126 Kilburn Ave. Rocklord, IL 61101

Difco Laboratories P.O. Box 1056-A Detroit, MI 48232

Diversey/Wyandotte 1532 Biddle Ave. Wyandotte, MI 48192 Eastern Crown, Inc. P.O. Box 216 Vernon, N.Y. 13476 FRM Chem, Inc. P.O. Box 207 Washington, MO 63090 GAF

1361 Alps Road Wayne, NJ 07479 Gerber Products Co.

445 State St. Fremont, MI 49412 Gist-Brocades USA

P.O. Box 241068 Charlotte, NC 28224 H. B. Fuller Co.

M. B. Filner Ca. Monarch Chemicals Div. 3900 Jackson St. NE Minneapolis, MN 55421

IBA Inc. 27 Providence Rd. Milibury, MA 01527

Kendali Co. One Federal St. Boston, MA 02101

Klenzade Division Economics Laboratory, inc. 3050 Metro Drive Suite 208

Bloomington, MN 55420

Maryland & Virginia Milk Producers Assn., Inc.

P.O. Box 9154 Rosslyn Station Arlington, Virginia 22209

Mid America Dalrymen, Inc. P.O. Box 1837 SSS 800 W. Tampa Springfield, MO 65805

Neige Co. P.O. Box 365 Rochester, NY 14602 Nasco International 901 Janesville Ave. Fort Alkinson, Wisconsin 53538

National Mastitle Council

1840 Wilson Blvd. Arlington, VA 22201

National Milk Producers Federation 1840 Wilson Blvd. Arlington, VA 22201

National Sanitation Foundation P.O. Box 1468 Ann Arbor, MI 48106 Norton Co. P.O. Box 350 Akron. Ohio 44308

Oxold USA, Inc. 9017 Red Branch Rd. Columbia, MD 21045

Penicillin Assays, inc. 36 Franklin St. Malden, MA 02148

Seiberling Associates, Inc. 11415 Main St. Roscoe, IL 61073

P.O. Box 2650 West Chester, PA 19380 3M/Medical-Surgical Div. 225-5S-01 3M Center

SmithKline Animal Health Products

United Industries, Inc. 1546 Henry Avenue Beloit, WI 53511

St. Paul, MN 55144-1000

Universal Milking Machine Div. Universal Cooperatives Inc. 408 S. First Ave. Albert Lee, MN 56007

Walker Stainless Equipment Co. 601 State St. New Lisbon, WI 53950

Copyright\* 1984, International Association of Milk, Food, and Environmental Sanitarians

JOURNAL OF FOOD PROTECTION, VOL. 49, JANUARY 1986

Hams were subsequently removed from the molds and cut into pieces approximately  $5 \times 11.4 \times 11.4$  cm. Hams were vacuum-packaged in retort-pouches (Reynolds Aluminum C., Mount Vernon, Ohio) of dimensions  $30.5 \times 45.7$  cm and consisting of three layers: 48 gauge polyester, .0007 in. foil, 4 mils polypropylene. A Roschermatic (Osnabrück, West Germany) model VM 20 vacuum sealer was used for packaging.

Storage. For experiment 1, 72 hams were used. Eighteen hams were placed in each of two coolers which were set at  $1 \pm 1^{\circ}$ C and  $6 \pm 1^{\circ}$ C. The remaining 36 hams were suspended from wires in a retort and subjected to a 10-min steam treatment at 121°C and 15 PSI. After cooling for 24 h at 4°C, 18 of these hams were placed in a cooler at  $1 \pm 1^{\circ}$ C and the remaining 18 in a cooler set at  $6 \pm 1^{\circ}$ C. For experiment 2, 50 hams were further-processed at 121°C for 10 min before being placed in the cooler at  $6 \pm 1^{\circ}$ C. An additional 25 hams were stored at the same temperature without the additional heat treatment.

Bacteriology. The following sampling plan was employed for bacteriological examination of each sample: (i) Surfaces: A 10cm2 template was made by cutting a circular hole in a small metal spatula. This device was flamed with alcohol between samplings. Surfaces were swabbed using sterile cotton tipped applicator sticks and 10 ml of sterile 0.1% peptone diluent (Difco). Two 10-cm<sup>2</sup> areas were swabbed on each large end of each ham sample. The applicator sticks were rinsed in the same blank between each swabbing. A total surface sample of 40 cm<sup>2</sup> was obtained by this method. One area on each of the remaining 4 sides was similarly swabbed to obtain a second pooled 40-cm<sup>2</sup> sample. (ii) Blended samples: Samples (33 g) were aseptically removed from the center of each ham sample with an alcohol-flamed sharp knife and blended with 297 ml of sterile 0.1% peptone diluent in sterile 1.25-L blender jars for 1 min.

The swab rinsings and blended samples were subjected to the following microbiological analyses using the pour plate method. (a) The aerobic mesophilic (SPC 32) and psychrophilic (SPC 4) populations were estimated by incubation at 32°C for 48 h and at 4°C for 10 d on Standard Plate Count agar (Difco). (b) Enumeration of lactobacilli was performed using MRS agar (Oxoid) incubated at 25°C for 5 d (MRS). (c) Isolation of enterococci was achieved on Enterococcus agar (Difco) incubated at 35°C for 72 h (ENT).

All dilutions were plated in duplicate. Three hams from each treatment were subjected to these analyses on a monthly basis.

oculated pack studies

Inoculated hum studies. Clostridium sporogenes (ATCC 7955) spores were harvested from beef heart infusion broth by the method of Goldini et al. (3). The spore suspension was washed 10 times in sterile M/15 sodium phosphate buffer (pH 7.00) and stored at 4°C. Spores were used within a month of harvesting. Microscopic examination of the suspension revealed less san 5% vegetative cells. Following a 15-min heat shock at 80°C. enumeration was done by plating on PA 3679 agar rodified according to Grischy et al. (5). Plates were incubated an anaerobic jar under CO<sub>2</sub> at 30°C for 10 d.

Ham was formulated as described above. Before cooking, the pumped and tumbled muscles were ground using a 12.7-mm plate. Ground meat and brine were weighed and placed in a large ribbon mixer. An appropriate dilution of the spore crop was added to the mixer to yield a total load of 100 spores per gram of raw ham. After mixing for 30 min at room tempera-

ture, the ham was stuffed into dual molds, processed at  $76^{\circ}$ C to an internal temperature of 71°C and chilled overnight. The cooked hams were cut into 100 pieces (3  $\times$  11.4  $\times$  11.4 cm) and the pieces were individually vacuum-packaged.

Storage. Fifty hams were placed in an incubator at 30  $\pm$  1°C without further-processing. The remaining 50 were subjected to a 121°C treatment for 10 min in a retort, chilled overnight at 5°C and placed in the incubator at 30  $\pm$  1°C.

Bacteriological evaluation. Every 10 d packaged hams were inspected visually for swollen packages or loss of vacuum. In all hams displaying symptoms of spoilage, 33-g samples were aseptically removed from the ham and blended with 297 ml of sterile 0.1% peptone water for I min and subjected to the following microbiological analysis: vegetative C. sporogenes cells were enumerated by plating on modified PA 3679 agar followed by incubation at 30°C for 10 d in an anaerobic jar.

#### **RESULTS AND DISCUSSION**

In experiments 1 and 2, the pasteurized hams that had been reheated at 121°C for 10 min did not show any evidence of spoilage over the 6- and 12-month storage periods investigated. (Tables 1,2,3). Pasteurized hams which did not receive a further heat treatment and which were stored at I ± 1°C developed microbial populations exceeding  $3.0 \times 10^8$  gm and  $3.0 \times 10^8$ /cm<sup>2</sup> on the surface for mesophiles (SPC 32), psychrophiles (SPC 4) and lactobacilli (MRS) after 3 months of storage (Table 1). The microbial loads of unheated pasteurized hams stored at 6 ± 1°C in experiment 1 (Table 2) exceeded these values about 1 month earlier than those stored at 1 ± 1°C. In experiment 2, the microbial loads of untreated hams exceeded 106/cm<sup>2</sup> on the surface after 5 months in storage at 6 ± 1°C (Table 3). The different spoilage rates observed for unheated hams in these two experiments can be attributed to variations in the initial bacterial loads in the pasteurized product and especially to different levels of contamination of the various ham surfaces in handling during packaging.

Our data indicate that a 10-min treatment at 121°C was effective in extending the microbiological stability of pasteurized ham under refrigerated storage. Low storage temperatures contribute significantly to safety and stability of cured meat products (1,7,14). Refrigerated storage temperatures tend to inhibit growth of spoilage bacteria as well as spore germination. An exception has been reported, however, for Clostridium botulinum type E which can germinate at temperatures as low as 3.3°C (4,6). These studies were all done in laboratory media. There is a lack of information in the literature regarding germination and growth of Bacillus and other Clostridium species in cured mear products at refrigeration temperatures. At this time, it appears that the single most important factor in preservation of cured meats is the low indigenous spore and heat-resistant cell populations in these products (1). None of the samples we examined displayed evidence of spoilage. The combination of low storage temperature and a low initial spore load along with the heat treatment applied to the surface of the hams to eliminate surface contaminating microorganisms led to the excellent refrigerated shelf-life observed in the course of these studies.

Table 4 gives results for the inoculated pack experiment. All of the samples showing evidence of swells were found t be positive for *C. sporogenes*. The pasteurized hams without additional heat treatment spoiled rapidly. After 30 d in storage 32% of the samples were

swollen and the remainder showed evidence of spoilage in the form of loss of vacuum r a soft, mushy consistency. Hams reheated at 121°C for 10 min swelled at a slower rate. Only 20% of the samples were spoiled after 30 d. These results show that the described process (10) cannot yield a shelf-stable product but may have some value in retarding the rate of spoilage due to growth of sporogenous organisms.

TA

less it i: ture per

ti·:

t: :

16.

a: u:

TABLE 1. Experiment 1: Numbers of microorganisms on hams stored at 1 ± 1°C. Means of three samples plated in duplicate are shown.

	•		Pasteurized hams		Ha	ms treated at 121	c
		Side	End	Blend	Side	End	Blend
Month	Assay	(cfu²/cm²)	(cfu/cm²)	(cfu/g)	(cfwcm²)	(cfu/cm²)	(cfu/g)
0	SPC 32	<b>≱b</b>	•	*	•	*.	•
•	SPC 4	•	•	. •	•		•
	MRS	•	•	•		•	.•
	ENT		• ]		•	•	
1	SPC 32	52	NS°	•	•	•	•
	SPC 4	•	NS			•	•
and the second second	MRS	•	•		•		
	ENT			•		•	•
2	SPC 32	52	•		•	•	
ia .	SPC 4	•	•		•	•	
	MRS	•	•		•	•	•
	ENT	•	•	•	•	•	. •
3	SPC 32	>3×10 <sup>8</sup>	$>3\times10^8$	>3×10 <sup>8</sup>	*	*	•.
	SPC 4	>3×10 <sup>8</sup>	>3×10 <sup>8</sup>	$>3 \times 10^{8}$		• .	•
	MRS	>3×10 <sup>8</sup>	>3×10 <sup>8</sup>	>3×10 <sup>8</sup>	and 🛊 and a	*	
	ENT	• •	• • •		•	•	•
4,5,6		Cor	ents discontinued		₩,	•	• * * * * * *

<sup>\*</sup>cfu = colony forming units.

TABLE 2. Experiment 1: Numbers of microorganisms on hams stored at 6 ± 1°C. Means of three samples plated in duplicate are shown,

are snown.								
			Pasteurized hams			Har	ns treated at	121°C
		Side	End	Blend		Side	End	Blend
Month	Assay	(cfu³/cm²)	(cfu/cm²)	(cfa/g)	•	(cfu/cm²)	(cfu/cm²)	(cfo/g)
0	SPC 32	<b>≠b</b>	. *				•	*
	SPC 4	•	•			•	•	
	MRS		•	• .		. *	•.	
•	ENT	•	• • • • • •	•		•	•	•
1	SPC 32	300	300	300		•	1 .	•
	SPC 4	100	300	100		•		•
.* * - *	MRS	110	170	300			•	
. •	ENT	<30	80	50		•		
2	SPC 32	$2.2\times10^2$	$1.4 \times 10^6$	$3.1 \times 10^{6}$		•	*	•
•	SPC 4	1.5×10 <sup>5</sup>	4.3 × 10 <sup>5</sup>	$4.0 \times 10^{5}$		. •	•	and the second
•	MRS	$2.4\times10^5$	$1.4 \times 10^{6}$	3.0×10 <sup>6</sup>	٠.	•		He Committee
	ENT	*	•	•		*		
3	SPC 32	$>3 \times 10^8$	$>3 \times 10^{8}$	$> 3 \times 10^{8}$		•	• •	
•	SPC 4	1.8×10 <sup>6</sup>	8.0×10°	$>3 \times 10^{8}$		•		
•	MRS	>3×10 <sup>8</sup>	>3×10 <sup>K</sup>	$> 3 \times 10^{8}$		•		•
	ENT	•	*	*		•		
4,5.6		Cou	nts discontinued			*	•	•

<sup>\*</sup>cfu = colony forming units.

b\* = <30 colony forming units.

<sup>°</sup>NS = no sample.

<sup>=&</sup>lt;30 colony forming units.

TABLE 3. Experiment 2: Numbers of microorganisms observed on hams stored at  $6 \pm 1^{\circ}$ C over 12 months. Means of three samples plated in duplicate are shown.

		· <del></del>	Pasteurized ham	<u>s</u> .		Hams treated at 121℃				
	•	Side	End	Blend	Side	End	Blend			
Month	Assay	(cfu³/cm²)	(cfwcm²)	(cfu/g)	(cft/cm²)	(cfu.cm²)	(cfwg)			
0	SPC 32	*b	*	*	•					
	SPC 4		•	•	•	• ,	•			
	MRS	•	•	•						
	ENT	•	. •	•		•				
1	SPC 32	•	•	•	•					
	SPC 4	•	. •		<b>*</b>	•				
	MRS	*	* -	•	•	•				
	ENT		*		• .	•				
2	SPC 32	$3.0 \times 10^4$	3.0×10 <sup>4</sup>	7.7×103	•		•			
	SPC 4	•	40	$3.0 \times 10^4$						
	MRS	$3.0 \times 10^4$	$3.0 \times 10^{4}$	$3.4 \times 10^3$	•	•	•			
	ENT	•	•	*	•					
3	SPC 32	NS°					. •			
	SPC 4	NS			•		•			
	MRS	NS	· • •		•					
	ENT	NS								
4	SPC 32	$6.0 \times 10^4$	$7.5 \times 10^{4}$	$1.0 \times 10^{6}$	. •	•	•			
	SPC 4	NS	NS	NS	•	•	•			
•	MRS	$2.0 \times 10^4$	5.0×10 <sup>4</sup>	4.0×10 <sup>4</sup>	•		,			
**	ENT		•	*						
5	SPC 32	4.0×10 <sup>6</sup>	$1.0 \times 10^{7}$	9.0 × 10 <sup>9</sup>	•	•	•			
	SPC 4	$3.0 \times 10^{6}$	$4.8 \times 10^{6}$	$3.2\times10^5$	*	•				
	MRS	$5.0 \times 10^{6}$	$9.0 \times 10^{6}$	6.0×10 <sup>5</sup>	•					
•	ENT	•	*	*		•				
6,7,8,9.10,12	٠.	Co	unts discountinue	ed	* •	•				

<sup>\*</sup>cfu = colony forming units.

TABLE 4. Inoculated pack experiments: cumulative percentage if samples positive for spoilage due to growth of Clostridium sporogenes in inoculated ham stored at  $30 \pm 1^{\circ}$ C for 50 days.

Days	Pasteurized hams	Hams treated at 121°C
10	4	0
20	22	8
· <b>30</b>	32	20
50	100	44

According to Kueck et al. (10), canned ham subjected a two-step heating process similar to ours will show less than 2% spoilage after 60 d in storage. In addition, it is claimed that storing hams for up to 30 d at temperatures between 6 and 8°C before exposure to elevated temperatures will eliminate spoilage problems. This step is believed by the authors (10) to lead to tremendous depletion in the spore population through germination followed by autolysis because of conditions unfavorable for vegetative cell growth, and to increased residual nitrite levels

a result of a slower rate of depletion. The result of mese events would be a product in which the relative level of nitrite and spores is heavily weighted in favor of nitrite.

Although germination of spores at refrigeration temperatures is known to occur, it cannot be assumed that all spores will germinate during the storage period proposed by Kueck et al. (10). In addition, it is unlikely that nitrite inhibits all sporeforming microorganisms (16). The success of the process described in this patent (10) probably results from very low initial spore populations. Our results indicate that if the product is challenged with spores of C. sporogenes at a level of 100 per gram of raw cured meat, they will grow and extensive spoilage will result if ham is exposed to elevated temperatures.

#### CONCLUSIONS

The shelf-life of hams packaged in retort-pouches and subjected to a 10-min treatment at 121°C is longer than hams not subjected to the secondary heat treatment. Inoculated pack studies indicate that a process such as this cannot lead to shelf stability and that ham that has not been subjected to treatments sufficient to eliminate spores of both aerobic and anaerobic microorgansims should be refrigerated.

#### REFERENCES

- Duncan, C. L. 1970. Arrest of growth from spores in semi-preserved foods. J. Appl. Bacteriol. 33:60-73.
- 2. Gardner, G. A. 1983. Microbial spoilage of cured meats. In Food

b\* = <30 colony forming units.

<sup>&#</sup>x27;NS = no sample.

- microbiology; advances and prospects. The Society for Applied Microbiology, Symposium Series No. 11. Academic Press, New York
- Goldini, J. S., S. Kojima, S. Leonard, and J. R. Heil. 1980. Growing spores of PA 3679 in formulations of beef heart infusion broth. J. Food Sci. 45.467-475.
- Greez, N., and L. H. Arvay. 1982. Effect of temperature on spore germination and vegetative cell growth of Clostridium botulinum. Appl. Environ. Microbiol. 43:331-337.
- Grischy, R. O., R. V. Speck, and D. M. Adams. 1983. New media for the enumeration and detection of Clostridium sporogenes (PA 3679) spores. J. Food Sci. 48:1466-1489.
- Hauschild, A. H. W. 1982. Assessment of botulism hazards from cured meat products. Food Technol. 36:95-104.
- Holley, R. A. 1981. Review of the potential hazards from botulism in cured meats. Can. Inst. Food Sci. Technol. J. 14:183-195.
- Houben, J. H. 1982. Heat resistance of Streptococcus faecium in pasteurized ham. Fleischwirtschraft. 62:490-493.
- Kafel, S., and J. C. Ayres. 1969. The antagonism of enterococci to other bacteria in canned hams. J. Appl. Bacteriol. 32:217-232.
- 10. Kneck, D. R., A. T. Adams, and L. L. Froning, 1965. Process

- for ganned meat. US Putent No. 3,192,053.
- Labots, H. 1975. Estimation of the refrigerated shelf life of pasteurized canned cured ham using an incubation procedure. Eur. Meat Workers Congress. Sept. 1975, p. 67-69.
- Lechowich, R. V., W. L. Brown, R. H. Deibel, and I. I. Somers. 1978. The role of nitrite in the production of cannot cured meat products. Food Technol. 32:45-57.
- Milbourne, K. 1983. Thermal resistance of Loctobocillus viridescens in ham. Meat Sci. 9:113-119.
- Fivnick, H., H. W. Barnett, H. R. Nordin, and L. J. Rubin. 1969.
  Factors affecting the safety of canned, cured, shelf-stable luncheon meat inoculated with Clostridium boulinum. Can. Inst. Food Sci. Technol. J. 2:141-148.
- Pivnick, H. 1980. Curing salts and related materials. pp. 136-159.
   In J. H. Silliker (ed.). Microbial ecology of foods. Vol. 1.
   Academic Press, New York.
- Roberts, T. A., and C. E. Garcia. 1973. A note on the resistance of *Bacillus* species. faecal streptococci and *Salmonella ryphimurium* to an inhibitor of *Clostridium* species formed by heating sodium nitrite. J. Food Technol. 8:463-466.

bl se to el:

the day su to ca bo of

ta m

> c: &l T! cc !a

**;**::

::

## Effects of Blade Tenderization, Vacuum Massag Time and Salt Level on Chemical, Textural and Sensory Characteristics of Precooked Chuck Roasts

S. D. SHACKELFORD, J. O. REAGAN, T. F. MANN, C.E. LYON, and M. F. MILLER

#### ABSTRACT

he influence of blade tenderization (T), vacuum massage time (2, 3) and salt level (SL) (1.0, 1.25%) on the chemical, textural, and insory characteristics of precooked chuck roasts prepared from Trieps brachii (TRI) and Supraspinatus (SUP) muscles was investigated, ooking losses decreased and total yields increased with higher SL, hile T increased product fat content: T decreased Warner-Bratzler tear values for the bind site (junction between the two muscles) and in edge of the roast: Instron values for hardness and chewiness of it muscle tissue were decreased by blade tenderization. Sensory panel valuation showed that TRI had a more intense beef flavor and was one tender than SUP, while T improved first impression tenderness.

#### INTRODUCTION

HE LONG RANGE SURVIVAL of the beef industry in the tarketplace may well be dependent upon the industry's imrediate response in determining the present and future delands of the consumer and development of new types of roducts that will meet the demands of the consumer. Recent hanges in demographics such as the decrease in the average umber of persons per household have resulted in an increased eed for smaller cuts of meat (less than 2 lb). Moreover, a reater number of households are composed of families where oth adults work outside of the home. Thus, there has been n increase in the need for (precooked) products that require ttle preparation within the home. Along with these changes, iere has been growth in the percentage of our society that are ealth conscious. Therefore, a demand for products that are w in fat and sodium content has developed. The poultry idustry has increased per capita consumption by developing w fat, low sodium, health oriented products that are easy to repare and, thus, more nearly fit the needs of today's conamer than do the products offered by the beef industry.

Whole muscles or muscle pieces weighing more than 300 g an be recombined to form roasts by utilizing additives such salt in combination with blade tenderization, vacuum masiging and waterbath cooking (Mann et al., 1987). Booren et l. (1981) stated that blade tenderization is necessary when roducing sectioned and formed steaks from the less tender uscles from the beef carcass. Therefore, the need exists for 10 development of a precooked beef roast from whole beef uscles. The present study was conducted to determine the ffects of blade tenderization, salt level, vacuum massage time and muscle type on the chemical, textural and sensory charteristics of precooked roasts made from whole chuck muscles.

uthors Shackelford, Reagan, and Miller are with the Animal & airy Science Dept., Livestock & Poultry Bldg., Meats & Muscle 'ology Section, Univ. of Georgia, Athens; GA 30602. Author on is with the USDA-ARS Richard B. Russell Agricultural Renarch Center, Athens, GA 30605. Author Mann's present adess: Oscar Mayer Co., P.O. Box 7188, Madison, WI 53707.

#### **MATERIALS & METHODS**

#### Roast beef preparation

Thirty-two Triceps brachii (TRI) and 32 Supraspinatus (SUP) muscles were obtained from three piece chuck combos at a commercial processing facility and then transported approximately 60 km to the USDA-ARS Richard B. Russell Agricultural Research Center in Athens, GA. The muscles were trimmed practically free of fat and essentially all connective tissue was removed from the TRI, while the exterior heavy connective tissue was removed from the Supraspinatus.: One-half of each muscle type group was blade tenderized by two passes through a Ross Blade Tenderizer (Model TC700M, Ross Industries, Inc., Midland, VA) and then all of the muscles were cut in half. A solution was prepared (based on raw meat weight) containing 10% added deionized water, 0.5% Roast Beef pump (Blend W-8639 A. C. Legg, Co., Inc. Birmingham, AL), 0.5% natural beef flavor (International Flavors and Fragrances, Inc., New York, NY), 0.5% Lem-O-fos (Stauffer Chemical Co., Food Ingredients Division, West-port, CT) and either 1.0 or 1.25% of a commercial grade salt depending upon treatment. The muscles were tumbled either 2 or 3 hr in a Rochermatic TU 120 vacuum massager (Robert Reiser & Co., Inc. Canton, MA) at -0.95 atm pressure. Following tumbling, two halves of each muscle type were place.

basts were then transferred to 68±1°C water bath and held for a period of time according to the following schedule: <1100g—20 min; 1100–1200g—25 min; >1200g—30 min. Roasts were allowed to chill for approximately of the post-cooking and then the Rub (Blend W-8640 A. C. Legg. Co., inc. Birmingham, AL) was applied to the surface at a level of 0.25% of the cooked weight.

The roasis were the first for a maximum of 180 d until utilized for further analysis. Two roasts of each treatment muscle combination were prepared. One roast was used for proximate analyses, salt and objective texture determination while the other roast was utilized for sensory panel evaluation.

#### Sensory analysis

A total of 15 people were screened for their ability to recognize differences between roast samples by triangle testing according to the procedure of Cross et al. (1978). Slices of roasts that had been stored at  $-34 \pm 1^{\circ}$ C were used for screening. A total of 11 people, who were able to recognize like samples during triangle testing, were accepted for training.

Seven training sessions (30 min/session) were held in which panelists were served slices from a variety of roasts to familiarize them with a wide range of sensory characteristics. These included roasts of the two muscle types of all eight treatments. Roasts were sliced, wrapped in aluminum foil and held overnight in a 1.7°C cooler. Samples were reheated in a commercial microwave oven prior to serving. Samples were scored on a 1 to 8 point scale for initial juiciness, sustained juiciness, first impression tenderness, overall tenderness and flavor intensity (1 = extremely dry, tough or bland, 8 = extremely juicy, tender or intense). In addition, panel members indicated whether or not they detected any off flavors.

Roasts were removed from vacuum packages and 2.54 mm thick slices were cut from the center portion of each roast until 8 to 12

#### PRECOOKED RECOMBINED CHUCK ROASTS . . .

slices were obtained. These slices were cut in half by cutting through the bind line of each slice. Then each portion was trimmed to provide 4 to 6 equal sized pieces per half slice. During screening and training sessions, plates of each sample were heated in a Litton microwave oven set at 30% power for 1.5 min. Training sessions were concluded when panelists were in close agreement (i.e. individual raw scores did not vary more than  $\pm 1$  from mean raw score and all panelists agreed they were comfortable with the scoring system).

Panelists sampled two replications of two muscle types of the eight treatment combinations. In order to eliminate muscle effects, roasts prepared from the TRI were sampled in the morning sessions and roasts prepared from the SUP were sampled in the afternoon session. Panelists were given a maximum of six samples per sission. Thus, there was a total of six sessions.

Panelists sat in booths in an isolated room free of distractions. Green fluorescent lighting was used to provide a greenish cast in the room. Panelists were instructed to drink room temperature water and apple juice to cleanse the palate between samples. Samples were reheated in a microwave oven for 15 to 45 sec (depending on plate load———one to three plates) and served on paper plates with randomly assigned code numbers.

#### **Proximate composition**

Values for moisture, fat (ether extractable component) and protein (Kjeldahl nitrogen) were determined using standard AOAC (1980) procedures. All determinations were performed in duplicate.

#### Caloric content

Caloric content per 85g serving was estimated by the equation: [(% Fat • 9.45) + (% Protein • 5.65)] • [0.85125].

#### Salt

Salt analysis as chlorine was performed in duplicate by the Volhardt volumetric procedure for chlorine, a modified AOAC (1980) method. The modification involved the substitution of potassium thiocyanate for ammonium thiocyanate.

#### Yield

Pump yield was determined as the weight of the pumped muscle divided by the weight of the raw muscle. Cook loss was determined as the difference between the weight of the pumped muscle and the weight of the cooked roasts divided by the weight of the pumped muscle. Total yield was determined as the weight of the cooked roast divided by the weight of the raw muscle.

#### Objective texture measurements

Slices approximately 2.54 cm thick were obtained from the center of each roast and were thawed overnight at 1.7 ± 1°C. The method of Bouton et al. (1971) was used to obtain objective texture measurements. An Instron Model 1122 equipped with a Microcon computer (Instron Corp., Canton, MA) connected to a 100 kg compression load cell and a 0.95 cm diameter flat ended stainless steel plunger was used to vertically compress (with the grain) the beef samples to exactly 80% of the original height of the muscles. Test conditions included: a full scale load of 10 kg, a crosshead speed of 20 mm/min, and a chart speed of 50mm/min. Two compressions were performed in each test location. Attributes measured included hardness (maximum force in kg required for initial compression), cohesiveness (ratio of the active work done under the second compression curve to that done under the first compression curve) and chewiness (hardness • cohesiveness). In order to determine the binding strength between the two pieces of muscle in each roast, two types of measurement were obtained: Bind Line—those measurements taken along the muscle junction; or Muscle Tissue—those measurements taken away from the bind line in the center of each muscle piece. Each measurement was done in triplicate.

Warner-Bratzler shear values were determined on six cores (1.27 cm in diameter) obtained from a 2.54 cm thick slice removed from the center of each roast. Three of the cores were taken at the bind line site and three additional cores were obtained immediately adjacent to the edge of each slice.

#### Statistical analysis

The data were analyzed as a function of four main effects (muscle type, blade tenderization, salt level and vacuum massage time) and all possible two-way interactions by the General Linear Models Procedure of the Statistical Analysis System (1986). When a main effect or interaction was significant, means were separated by a comparison of least-squares means. The predetermined level of significance of P < 0.05 was used for all comparisons.

#### **RESULTS & DISCUSSION**

AS SALT LEVEL (SL) increased, protein content decreased due to the dilution of the protein content caused by the greater water-retaining ability of the higher SL roasts. SL did not affect any of the other proximate parameters. This is in partial agreement with the work of Hamm (1970) that showed that when salt level increased, water-holding capacity increased and protein and fat content decreased. Blade tenderization (T) increased fat content but did not affect moisture or protein content. Although there were no main effects of vacuum massage time (VMT) and muscle type (MT) on any of the proximate parameters, they did interact with one another to affect the fat content of the roasts. As VMT was increased, the fat content of roasts prepared from TRI decreased while an opposite effect was seen in SUP (Table 1). A possible explanation of this interaction is that TRI muscles were higher in fat content and lower in protein content prior to vacuum massaging, but after extended vacuum massaging, TRI muscles could not bind as much of the fat which was excised during massaging because of their lower initial protein content. The proximate composition, caloric content and salt content of the roasts as affected by treatment combination are given in Table 2. Mean composition of the roasts across all treatment combinations was; 73.08% moisture, 2.35% fat, 21.63% protein, 122.9 CAL/85g serving and 1.2% salt.

SL was the only factor to affect salt content of the roasts as

Table 1 - Interaction of vacuum massage time and muscle type on percent fat contents of the roasts

VMT	:	Triceps Brachii	Supraspinatus
2 hr		2.94	2.34
3 hr		1.80	2.548

Standard error of the mean is 0.3

Table 2—Least-squares means of proximate composition as effected by treatment\*

	Treat	ment <sup>b</sup>		Moisture	Fat	Protein	Cal/85q	Salt
T	SL	VMT	MT	(%)	(%)	(%)		(%)
1	1	1	1	71.0	3.2	22.2	132.2	1.0
1	1	1	2	73.5	2.5	21.3	122.0	- 1.1
1	1	2	1	74.3	2.1	22.7	126.0	1.0
1	1	2	2	71.9	3.6	22.1	135.3	1.1
1	2	1	1	72.3	3.3	21.8	131.2	1.2
1	. 2	1	2	73.4	2.1	22.0	122.5	1.4
1	2	2	1	74.0	2.9	20.3	120.4	1.5
1	2	2	2	74.0	2.6	20.6	119.8	1.4
2	1	1	1	72.9	2.5	21.5	123.4	1.0
2	- 1	1	2	71.9	1.3	22.7	119.2	1.0
2	i	2	1	72.5	2.2	22.6	125.9	1.0
2	1	2	2	74.1	1.8	21.4	117.3	1.1
2	2	1	1	72.3	2.4	20.7	119.0	1.2
Ž	2	1	2	73.7	1.2	21.3	112.0	1.4
2 .	2	2	1	72.8	2.0	22.0	121.5	1.2
2	2	2	ż	74.7	2.0	21.3	118.6	1.2
SEM	-	-	-	1.1	0.7	0.5	7.4	0.1

Moisture, fat, protein, caloric and saft content were not significantly different across all treatment combinations (P > 0.05).

b VMT is vacuum massage time.

A Means bearing different superscripts are significantly different (P < 0.05).

T = Tenderization (1 = tenderized, 2 = nontenderized)

SL = Added salt level (1 = 1.0%, 2 = 1.25%)

VMT = Vacuum massage time (1 = 2 hr, 2 = 3 hr)
MT = Muscle type (1 = Triceps brachii, 2 = Supraspinatus)

<sup>\*</sup> SEM is the standard error of the mean.

the high SL roasts had a greater salt content than the low SL roasts. None of the main effects or two-way interactions affected pump yield. All of the pump solution was absorbed by each treatment combination during tumbling. Therefore, there was no variation in pump yield between treatment combinations. Higher SL resulted in decreased cooking losses and increased total yields. The relationship of SL to yield has been reported by numerous researchers in many types of processed meats including the work of Mann (1987) which showed that recombined beef roasts increased significantly in yield as salt level was increased from 0 to 1.0%. The increased yields associated with added salt are mainly due to the decreases in cooking losses affected by the greater water holding capacity of products high in salt content (Schwartz and Mandigo, 1975; Pepper and Schmidt, 1975; Mandigo, 1982; Brewer et al., 1984; Cordray and Huffman, 1984; Chow et al., 1986; Lamkey et al., 1986).

Tenderization decreased hardness of the bind-line and the muscle tissue, increased cohesiveness of the bind-line and increased chewiness of the muscle tissue (Table 3). Warner-Bratzler shear values for the bind-line and the edge of the roasts were decreased by blade tenderization (Table 4). These data coincide with the data of Lyon et al. (1983) which showed that mean shear force values were generally lowered by blade tenderization. This is evidence of the physical disruption of the muscle fibers and the muscle connective tissue caused by blade tenderization. T could have allowed for a greater hydration of muscle fibers, therefore, increasing muscle tenderness. T and MT interacted to effect Warner-Bratzler shear values for the bind-line (Table 5). Roasts prepared from nontenderized, SUP muscles had higher shear values for the bind than did roasts prepared from nontenderized, TRI muscles. Roasts made from tenderized muscles of either MT were equal in their shear values for the bind-line. This is evidence of the role of blade tenderization in decreasing the effects of connective tissue. Flores et al. (1986) showed that although blade tenderization was not as effective as trimming of connective tissue in removing the effects of connective tissue in precooked roasts, it

Table 3 - Influence of blade tenderization on objective texture parameters

	Tenderized	Nontenderized	SEM*
Bind line Hardness (kg)	3.28	3.8^	0.2
Cohesiveness	0.53^	0.51	0.01
Chewiness (kg)	1.7	1.9	0.1
Muscle tissue			
Hardness (kg)	4.78	5.7^	0.2
Cohesiveness	0.55	0.55	0.01
Chewiness (kg)	2.5	3.0^	0.2

SEM is the standard error of the mean.

Table 4-Influence of blade tenderization on Warner-Bratzler shear val-

<i>ues</i>	Tenderized	Nontenderized	SEM
Bind line	1.2 <sup>6</sup>	2.0 <sup>A</sup> : .	0.1
Edge of roast	1.9 <sup>8</sup>		0.1

<sup>•</sup> Values are reported in kg force.

ing salah salah

Table 5—Interaction of blade tenderization and muscle type on Warner-Bratzler shear values of the bind-line

	Tenderized		Nontenderized	
Triceps brachii	1.3 <sup>c</sup>		1.78	
Supraspinatus	1.1 <sup>c</sup>	20.00	2.4 <sup>A</sup>	

Values are reported in kg force. The standard error of the mean is 0.2.

was a viable alternative to trimming for some restructured products, as it is less labor intensive and results in higher yields. T also interacted with VMT to affect shear values f r the bind-line (Table 6). T had a greater effect on decreasing the Warner-Bratzler shear values for the bind of roasts that had been massaged for 2 hr than those that had been massaged for 3 hr.

TRI had a more intense beef flavor and were more tender than SUP (Table 7). Paterson and Parrish (1986) sound similar differences in tenderness when comparing the same two muscles. T increased panel scores for initial tenderness but did not affect overall tenderness. There were no differences among SL's and VMT's for any of the sensory parameters. However, VMT interacted with SL to affect overall tenderness. Low SL treatments were more tender if VMT was increased, but roasts made from high SL were found to be more tender if VMT was decreased. Salt and vacuum massaging are both known to play a role in the solubilizing of salt soluble proteins. When an overabundance of salt-soluble proteins are solubilized, a rubbery bind results between the two muscle pieces which results in roasts that are very tough and chewy.

This value-added product, which makes use of chuck muscles, a relatively cheap source of raw materials, is more than 97% fat-free, contains less than 130 calories per 85g serving and has a muscle fiber alignment similar to that seen in whole cuts of meat. These factors combine to make this product desirable to the consumer and, thus, this product should be readily accepted in the retail case as well as in the hotel, restaurant and institutional trade.

#### CONCLUSION

TRICEPS BRACHII muscles were more suitable for use in whole muscle restructured roast beef products due to the lower cooking losses, more intense beef flavor and greater tenderness. However, Supraspinatus muscles were acceptable for use in this type of value-added product when blade tenderized. Although, nontenderized products were not as tender as tenderized roasts, both were within an acceptable range of tenderness. Higher yields and lower cooking losses were achieved by increasing the level of added salt; but this came at the sacrifice of increasing the level of sodium in the product. Although there were no significant main effects of vacuum massage time (VMT), VMT was found to interact with salt levels to affect tenderness. As the amount of salt added to product is increased, the length of VMT should be decreased to achieve greater tenderness. -Continued on page 905

Table 6-Interaction of blade tenderization and vacuum massage time on Warner-Bratzler sheer values of the bind line

Off Wallion -Did Elect Bridge		 
VMT	.Tenderized	Nontenderized
2 hr	1.1°	 2.4^
3 hr	1.3 <sup>c</sup>	1.8

<sup>\*</sup> Values are reported in kg force. The standard error of the mean is 0.2.

Table 7—Least-squares means of sensory panel scores\* as influenced by muscle source

mestic source			
	Initial	Overall	Flavor
Muscle source	tenderness	tenderness	intensity
Triceps brachii	6.6^	6.5 <sup>A</sup>	6.0^
Supraspinatus	5.90	5.8°	5.78
SEMP	0.1	0.1	0.1

<sup>\*</sup> Scored on an eight point scale. 1 = extremely tough or bland, 8 = extremely tender or intense.

AB Means in the same row bearing different superscripts are significantly different (P < 0.05).

b SEM is the standard error of the mean.

A8 Means in the same row bearing different superscripts are significantly different (P < 0.05).

Asc Means in the same row bearing different superscripts are significantly different (P < 0.05).

ABC Means bearing different superscripts are significantly different (P < 0.05).

SEM is the standard error of the mean.

AB Means in the same column bearing different superscripts are significantly different (P < 0.05).

#### CONCLUSION

THERMORADIATION was an effective means for producing a Salmonella-free LWE product and showed great promise for yielding a sterile product. The Salmonella inactivation occurred at a faster rate when using higher temperatures, lower initial cell numbers and lower pH values, indicating that manipulation of these parameters combined with aseptic packaging might produce a product stable at ambient temperatures.

#### REFERENCES

Ajlouni, S. and Hamdy, M. K. 1988. Effect of combined gamma-irradiation and storage on biochemical changes in sweet potato. J. Food Sci. 53: 477. Anonymous. 1983a. Legal considerations concerning food irradiation. Food Technol. 37(2): 38.

Anonymous, 1983b. Radiation preservation of foods. Food Technol. 37(2):

Anonymous, 1986a. Food irradiation rules close to approval. ASM News 52(2): 84.

(心明 五四百萬本

Anonymous. 1986b. Irradiation in the production, processing, and han-

Anonymous. 1986b. Irradiation in the production, processing, and handling of food. Fed. Reg. 51(75): 13376.

Ball, H. R., Hamid-Samimi, M., Foegeding, P. M., and Swartzel, K. 1987. Functionality and microbial stability of ultrapasteurized aseptically packaged refrigerated whole egg. J. Food Sci. 52: 1212.

Bruhn, C. M., Sommer, R., and Schutz, H. G. 1986. Effect of an educational pamphlet and posters on attitude toward food irradiation. J. Ind. Irrad. Technol 4(1): 1.

CDHS. 1988. Egg-breaking machines not banned in California: Advisory issued. Food Chem. News 29(52): 11.

Comer, A. G., Anderson, G. W., and Garrard, E. H. 1963. Gamma irradiation of Salmonella species in frozen whole egg. Can. J. Microbiol. 9: 321. FDA. 1971. The Egg Products Inspection Act. Fed. Reg. 36: 3814. FDA. 1988. Salmonella outbreaks linked to eggs. The Cauldron 11(1): 6. Foegeding, P. M. and Stanley, N. W. 1987. Growth and inactivation of microorganisms isolated from ultrapasteurized egg. J. Food Sci. 52: 1219. Heath, J. L. 1988. Irradiation: alternative to bacterial control. Broiler Ind. 2. 14. P. C. 1967. Mand. Advisory in the salmonel of the control of the control

Hofer, K. G. 1987. Heat potentiation of radiation damage versus radiation potentiation of heat damage. Radiat. Res. 110: 450. IFT's Expert Panel on Food Safety and Nutrition. 1983. Radiation Preservation of Foods—A Scientific Status Summary. Krystynak, R. 1986. Food irradiation: an economic perspective. (Canadian) Food Market Comm. 8(3): 17.

Kvenberg, J. E. and Archer, D. L. 1987. Economic impact of colonization control on foodborne disease. Food Technol. 41(7): 77.

Lapidot, M. 1979. Radicidation and radappertization of animal feeds in Israel, 1968–1977. In "Decontamination of Animal Feeds by Irradiation," p. 43. International Atomic Energy Agency, Vienna.

Maeda, K., Ito, K., and Yamaguchi, N. 1980. A simple lysoplate method of lysozyme determination with samples dried on filter paper: Clin. Chim.

of bysozyme determination with samples dried on filter paper: Clin. Chim. Acta 100; 175.

Mayes, F. J. and Takehalli, M. A. 1983. Microbial contamination of the hen's egg: a review: J. Food Protect. 46: 1092.

Modak, R. S. 1987. Calls for industry endorsement of irradiation in consumer publications. Food Technol. 41(12): 32.

Pallas, J. E. and Hamdy, M. K. 1976. Effects of thermoradiation on bacteria. Appl. Environ. Microbiol. 32: 250.

Roskey, C. T. and Hamdy, M. K. 1972. Bruised poultry tissue as a possible source of Staph infection. Appl. Microbiol. 23: 683.

SAS. 1985. "SAS Procedures Guide for Personal Computers," 6. SAS Institute Inc., Cary, NC.

Sauter, E. A. and Peterson, C. F. 1974. The effect of egg shell quality on penetration by various Salmonallas. Poultry Sci. 53: 2159.

Shafi, R., Cotterill, O. J., and Nichola, M. L. 1970. Microbial flora of commercially pasteurized egg products. Poultry Sci. 49: 578.

Shamsuzzaman, K. 1988. Effects of combined heat and radiation on the survival of Clostridium sporagenes. Radiat. Phys. Chem. 31: 187.

Shugar, D. 1952. The measurement of lysoxyme activity and the ultraviolet inactivation of lysoxyme. Biochim. Biophys. Acta 8: 302.

Thayer, D. W., Christopher, J. P., Campbell, L. A., Ronning, D. C., Dahlgren, R. R., Thomson, G. M., and Wierbicki, E. 1987. Toxicology studies of irradiation-sterilized chicken. J. Food Protect. 50: 278.

Tsuji, K. 1983. Low-dose cobalt 60 irradiation for reduction of microbial contamination in raw materials for animal health products. Food Technol. 37(2): 48.

noi. 37(2): 48.

Weiss, J., Allen, A. O., and Schwars, H. A. 1955. Use of the Fricke ferrous sulfate dosimeter for gamma-ray doses in the range 4 to 40 kr. Proc. of Int. Conf. on Peaceful Uses of Atomic Energy. 15: 179.

Welt, M. A. 1985. Barriers to widespread approval of food irradiation. J. Ind. Irrad. Technol. 3(1): 75.

Ms received 10/8/88; revised 1/30/89; accepted 2/11/89.

The authors thank the staff of the Center for Applied isotope Studies in Athens, GA, for the use of their Gamma Call 200. We also thank the staff of the UGA Poultry Feed Mill for donating the eggs used in this project. Special thanks go to Mr. Dale B. Harris, Jr. for statistical analyses of this work, and also to Kathy Webb and Dr. Mohan Rao.

#### PRECOCKED RECOMBINED CHUCK ROASTS... From page 845 -

#### REFERENCES

AOAC. 1980. "Official Methods of Analysis," 13th ed. Association of Of-

AUAL. 1980. "Cilical methods of Analysis, Total ed. Association of Cificial Analytical Chemists, Washington, DC.

Booren, A. M., Jones, K. W., Mandigo, R. W., and Olson, D. G. 1981. Effects of blade tenderization, vacuum mixing, salt addition and mixing time on binding of meat pieces into sectioned and formed steaks. J. Food Sci. 46, 1979.

Bouton, P. E., Harris, P. V., and Shorthose, W. R. 1971. Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. J. Food Sci. 36: 435.

Brewer, M. S., Field, R. A., Williams, J. C., Miller, G. J., Cross, H. R., and Secrist, J. L. 1984. Qualities of chunked and formed lamb roasts. J. Food

Sci. 49:1376.
Chow, H. M., Ockerman, H. W., Cahill, V. R., and Parrett, N. A. 1986.
Evaluation of cured, canned pork shoulder tissue produced by electrical stimulation, hot processing and tumbling. J. Food Sci. 51: 288.
Cordray, J. C. and Huffman, D. L. 1984. Update: Restructured Products.
Proc. 26th Annual Meat Science Institute, March 18-21. p. 90.
Cross, H. R., Moen, R., and Stanfield, M. S. 1978. Training and testing of judges for sensory analysis of meat quality. Food. Technol. 36: 48.
Flores, H. A., Kastner, C. L., Kropf, D. H., and Hunt, M. C. 1986. Effects of blade tenderization and trimming of connective tissue on hot-boned,

of blade tenderization and trimming of connective tissue on hot-boned, restructured, pre-cooked roasts from cows. J. Food Sci. 51: 1176. Hamm, R. 1970. Properties of meat proteins. In "Proteins as Human Food." p. 167. AVI Publishing Co., Westport, CT. Lamkey, J. W., Mandigo, R. W., and Calkins, C. R. 1986. Effect of salt and

phosphate on the texture and color stability of restructured beef steaks. J. Food Sci. 51: 873.

Lyon, M. C., Kastner, C. L., Dikeman, M. E., Hunt, M. C., Kropf, D. H., and Schwenke, J. R. 1983. Effects of electrical stimulation, aging and blade tenderization on hot-boned beef pooss major and triceps brachii muscles. J. Food Sci. 48: 131.

Mandigo, R. W. 1982. Restructured Meat Products. Ch. 5. Proc. International Symposium Meat Science and Technology, K. R. Franklin and H. R. Cross (Ed.): p. 235. Award Printing Co., Chicago, IL.

Mann, T. F. 1987. Texture, chemical and sensory characteristics of precoked beef chuck roasts as influenced by boning time, salt level and the addition of antioxidants. Ph.D. dissertation, Univ. of Georgia, Athens. Mann, T. F., Reagan, J. O., Lillard, D. A., and Campion, D. R. 1987. Chemical and sensory characteristics of precooked beef chuck roasts as influenced by the addition of antioxidants. Proc. 40th Ann. Recip. Meat Conf. p. 156.

p. 156.
Paterson, B. C. and Parrish, F. C., Jr. 1986. A sensory panel and chemical analysis of certain beef chuck muscles. J. Food Sci. 51: 876.
Pepper, F. H. and Schmidt, G. R. 1975. Effects of blending time, salt, phosphate and hot-boned beef on binding strength and cook yield of beef rolls. J. Food Sci. 40: 227.
SAS. 1986. "SAS User's Guide: Statistics." SAS Institute, Inc. Cary, NC. Schwartz, W. C., and Mandigo R. W. 1975. Salt and sodium tripolyphosphate effect on storage of restructured pork. J. Anim. Sci. 41: 301.
Ms received 8/10/88; revised 10/28/88; accepted 2/10/89.

A 10:04

Journal of Foud Protection, Vol. 56, No. 12. Pages 1034-1038 (December 1993) Copyrighto, International Association of Affilia, Food and Environmental Senitarians

PREMIETI SCILING

#### Reduction of Listeria monocytogenes in Precooked Vacuum-Packaged Beef Using Postpackaging Pasteurization

D. KAY COOKSEY\*\*, BARBARA P. KLEIN1, FLOYD K. MCKEITH2, and HANS P. BLASCHEK2

Division of Fronts and Nurtison. Department of Animal Sciences, and Department of Food Science, University of Illinois, Urbana, minute 61801

(Received for publication August 7, 1992)

#### ABSTRACT

Precooked beef loin chunks were inoculated separately with three strains of Listeria monocytogenes (Scott A, 101M, and 103M). Uninoculated chunks served as controls. All chunks were vacuum packaged after inoculation. Half were not pasteurized and half were pasteurized in R5°C water for 16 min. All samples were stored at 4°C for up to 85 d and examined periodically. Pasteurization reduced all microflora and significantly reduced populations of three strains of L monocytogenes on the surface and in the broth of the precooked beef chunks for 85 d of refrigerated storage as determined by direct plating procedures. All three strains of L monocytogenes were recovered from the inoculated pasteurized beer using enrichment. Uninoculated chunks were positive for Listeria spp. which were primarily Listeria welshimeri. Without pasteurization, microflora increased 5- to 6-fold within 14 d of storage. Populations of Scott A and 101M strains of L. manucytogenes increased significantly within 7 d. After 14 d. populations of all three strains did not differ from initial levels and remained unchanged for the remainder of the storage period.

Listeria monocytogenes and other Listeria spp. are commonly isolated from fresh and cooked meat. Brackett (4) reported that 70% of the ground beef in the United States was contaminated with L. monocytogenes. Others have reported levels of 58% (25) and 77.3% (13). A survey done by Grau and Vanderlinde (16) indicated that 53% of 175 vacuum-packaged, ready-to-eat meat samples contained Listeria spp. In another study, sliced precooked beef contained L. monneytogenes at a level of  $1.0 \times 10^2$  CFU/g (20). Listeria spp. were tound in 13-30% of a wide variety of ready-to-eat means sampled in Europe and Canada (18).

Boyle et al. (3) concluded that L monocytogenes can survive cooking to 70°C and refrigerated storage for 48 h when the initial cell concentration is greater than 105 CFU/g. According to Bhaduri et al. (2), exposure to 65.5°C for 1-2 min should be sufficient for the destruction of L. monocytogenes. Mackey and Bratchell (22) suggested that L monneytogenes was more heat resistant in meat than dairy products due to the lower water activity and protective effect of fat in meat.

Postprocess handling is considered to be the primary cause of contamination in precooked meat items. Since the

Menomonie, WI 54751.

tolerance policy for ready-to-eat meats, several ways to reduce the incidence of Listeria in meat have been suggested. These include implementation of HACCP (Hazard Analysis at Critical Control Points), use of antagonistic lactic acid bacteria, antimicrobial agents, and postpackaging pasteurization (12,14,26). Although there are reports of L. monocytogenes in

U.S. Department of Agriculture (USDA) issued a zero

heat-treated meats, most deal with fully cooked whole muscles. There is little information on portioned, precooked pasteurized meat. The objectives of this experiment were to determine the effect of postpackaging pasteurization and refrigerated storage has on the presence and growth of three different strains of L. monocytogenes in precooked vacuum-packaged beef loin chunks. In addition, indigenous Listeria spp. and microflora were identified.

#### MATERIALS AND METHODS

Processing procedure

Three USDA beef strip loins IMPS 180 (23), ranging in weight from 5.5-6.4 kg, were obtained through a local commercial source. The shipping puckages were removed, and the strip loins were trimmed of all subcutaneous fat before vacuum sealing (Koch Multivac AGW, Kansas City, MO) in CN 530 cook-in bags Cryovac Div., W. R. Grace, Duncun, SC), The puckaged meat was precooked in a steam jacketed kettle (Market Forge MT40, Everett, MA) set at 82°C to an internal temperature of 60°C (2 h cooking time). After precooking, the strip loins were removed from the steam kettle and cooled in ice to 4°C. The strip loins were removed from the vacuum package and cut into 2.5-cm thick steaks and further divided into Launks (50-g).

Precooked beef loin chunks were randomly assigned to me of four treatment groups (Fig. 1). Group I was uninoculated and served as the control. Group 2 was inoculated with L. monocytogenes Scott A strain. Group 3 was inoculated with L monocytogenes 101M, and group 4 was inoculated with L monocytogenes 103M. After inoculation, chunks were individually vacuum packuged in CN 530 bags and vacuum sented using a Reiser Model VM-T11 (Onesbrück, Germany) vacuum-packaging machine. The inoculation procedure is described in a later section.

Each treatment group was subdivided into pasteurization or nonpasteurization treatments. The nonpasteurized mest was immediately placed in a refrigerated retail display case (Hill Refrigeration Co., Model LMN 12TC, Los Angeles, CA) that maintained a temperature of 4°C. For pastcurization, meat was sub-

Present address: Packaging Technology, University of Wisconsin-Stout,

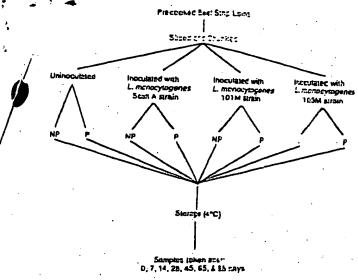


Figure 1. Experimental design flowchart (NP = nonpasteurized, P = pasteurized).

merged in water contained in a steam jacketed kettle set at 82°C for 16 min as determined by previous work done in our laboratory (10). The internal temperature of the chunks reached 60°C. After pasteurization, the chunks were cooled in ice and placed in refrigerated storage with the nonpasteurized meat. Samples from all treatment groups were taken after 0, 7, 14, 28, 45, 65, and 85 d of storage. Three replicate experiments were completed.

To monitor the temperature of the chunks during pasteurizalion, three uninoculated beef chunks had thermocouples inserted through stuffing boxes (Ecklund- Harrison Tech., Cupe Corral, FL) into the center and onto the exterior of the meat. The same chunks were placed in the retail display case to monitor the case temperature during storage. Thermocouples were attached to a datalogger (OM440, Omega Engineering Inc., Stamford, CT) to record the temperature every 2 min during pasteurization and cooling. The beef chunks that were used to monitor temperature were not used for microbiological analysis.

#### Inoculation procedure

The Scott A strain of L monocytogenes was obtained from Dr. Scott Martin (University of Illinois at Urbana-Champaign). L monocytogenes strains (sausage isolates) 101M and 103M were obtained from Dr. Michael Doyle (University of Georgia). All L monocytogenes cultures were grown and stored in tryptic soy broth (Difeo, Detroit, Ml) supplemented with 0.6% yeast extract. Cells were grown to mid-log phase and diluted in 0.1% peptone buffer to obtain an inoculum of 10° CFU/ml. Meat chunks were individually inoculated by placing them in sterile bags containing 50 ml of inoculum for 15 min on a shaking table. The chunks were removed from the inoculum using sterile forceps and placed in individual CN 530 cook-in bags and vacuum sealed.

#### Identification and enumeration

The surface of the chunks was sampled using a sterile swab and aluminum foil template (3 cm × 3 cm). The broth (purge remaining in the package) was sampled using a sterile pipet. Surface swab samples of the uncooked loin roasts were done to obtain baseline microflora levels prior to precooking.

Two methods, direct plating and enrichment, were used for isolation is L monocytogenes obtained from the surface and broth samples. Direct plating using modified Vogel-Johnson agar (8) llowed recovery of uninjured cells of L. monocytogenes from ninoculated and inoculated chunks. Results are reported as

log<sub>10</sub>/cm<sup>2</sup> for surface samples and log<sub>10</sub>/ml for broth samples of beef chunks.

After samples for direct plating were taken, the same samples (50-g chunks) were aseptically placed in a sterile bag containing 50 ral of University of Vermont enrichment broth (11) which allowed recovery of injured L monocytogenes. Although other media are now recommended for resuscitating injured cells (9). University of Vermont medium was considered superior for recovery of L monocytogenes from cooked meat products at the time this study was initiated (5.7). Because the repair of cells in enrichment broth allowed cells to increase in number and exceed the original level of cells present, the results were reported as positive or negative for the presence of Listeria spp. after enrichment.

Positive colonies (five per plate) obtained from modified Vogel-Johnson agar plates of uninoculated meat samples were used to identify the species of Listeria (21). A total of 35 isolates were chosen, three did not survive isolation on tryptic soy agar with year: extract (TSA-YE) plates. Of the 32 isolates selected for confirmation, eight were from the uncooked strip loins and 24 were from uninoculated, precooked, and pasteurized beef loin chunks. Gram stains, catalase and carbohydrate fermentation (dextrose, esculin, maltose, rhamnose, mannitol, and xylose), motility, reactions to methyl red/Voges-Proskauer and triple sugar iron slants were done according to the procedures described by Loven and Hitchins (21), Isolates were tested for hemolytic reaction using TSA plates supplemented with 5% sheep blood (BBL, Becton Dickillson and Co., Cockeysville, MD). The TSA sheep blood agar plates were also used for the CAMP test.

TSA (tryptic soy agar; Difco, Detroit, MI) was used for the total aerobic and total anaerobic plate counts for uninoculated chunks. Aerobic plates were incubated at 35°C for 48 h. Anaerobic places were placed in a chamber flushed with 80% N<sub>2</sub>, 15% CO, and 5% H, and incubated at 35°C for 48 h. Aerobic and anacrobic isolates (at least five per set of duplicate plates) were selected after incubation and chosen based on colony culor, opacity, form, elevation, and margin (1). Colonics were further screened using catalase tests and Gram stains. Isolates were streaked onto TSA slants, incubated at 35°C for 48 h, and used for further confirmatory tests. A Minitek Differentiation System Anaerobe II kit (Beeton Dickinson and Co.) and the Enterotube II System (Roche Diagnostic Systems, Montelair, NJ) were used to tentatively identify indigenous bacteria. Other confirmatory tests were done depending on the results of tentative identification tests (catalase, Gram stain, oxidase and carbohydrate fermentation) and the recommendations listed in Bergey's Manual (19).

#### Statistics

Independent T tests were calculated to compare the microbial populations of pasteurized to nonpasteurized chunks at each day of storage. Comparisons were also made to determine the significance in population change over time using T tests. Data were converted to natural log to stabilize the variances.

#### RESULTS AND DISCUSSION

Inoculated strains of L. monocytogenes

Pasteurization decreased (P < 0.05) the population (Fig. 2) of L monocytogenes Scott A, 101M, and 103M on the surface and in the broth of precooked beef loin chunks compared to nonpasteurized chunks. This difference was maintained for 85 d of refrigerated storage (using direct plating). Overall, pasteurization reduced (P < 0.05) the levels of L monocytogenes by 10,000-fold on the surface and 1,000,000-fold in the broth. Populations for pasteurized meat remained unchanged during the 85 d of refrigerated

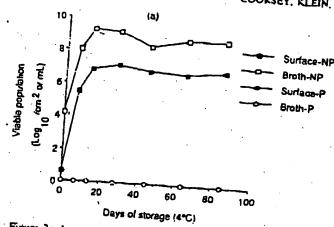


Figure 2a. L. monocytogenes (a) Scott A:b; 101M and (c) 103M on the surface and in the broth of precooked beef loin chunks during refrigerated storage. Data for pasteurized meat overlap. therefore, only one line is visible. (NP = nonpasteurized,

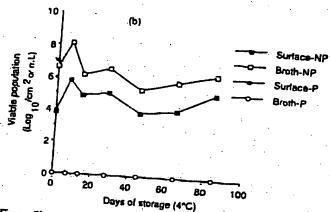


Figure 2b.

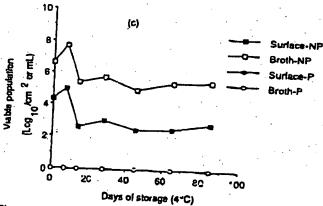


Figure 2c.

storage when direct plating methods were used. Boyle et al. (3) heated ground beef slurry inoculated with 7.84 log of in a 75°C water bath. It took 10.6 min to reach 65°C and caused 4.6- to 5.5-log reduction in population. After 13.6 min, the slurry reached 70°C and the cells had to be recovered with an enrichment procedure, thus enumeration will not possible.

Enrichment was necessary to recover all three inoculated strains of L monocytogenes on the surface and in the broin of pasteurized beef loin chunks after each sampling

interval during 85 d of storage (data not shown). Preliminury data done in our laboratory indicated that when a most probable number (MPN) procedure (7) was used to enumerate the samples, it was found that the levels of all three strains of L monocytogenes were very low tranging from <0.3 to < 50 MPN/cm<sup>2</sup> or ml) throughout the 85-d storage period.

Nonpasteurized chunks (surface and broth) had higher (P < 0.05) levels of L. monocytogenes Scott A and 101M after 7 d compared to initial (0 d) levels (Fig. 2s and b). The population of L monocytogenes 103M (7 d) was not significantly higher than the initial population (Fig. 2c). After 14 d, the populations of all three strains either decreased or remained unchanged and were not different (P > 0.05) from initial levels for the remainder of the storage period. This corresponds to high levels of microflora (Fig. 3a and b). Grau and Vanderlinde (15) reported that indigenous L. monucytogenes population increased over 10,000fold in 14 d (stored at 4.8°C) and had a growth rate slightly less than that of the natural microflora. They also stated that Listeria population did not increase when microflora reached levels greater than 10° CFU/g.

Other studies state that levels of L monocytogenes remain constant during refrigerated storage in fresh meat and cooked meat. Shelef (24) found that Listeria remained

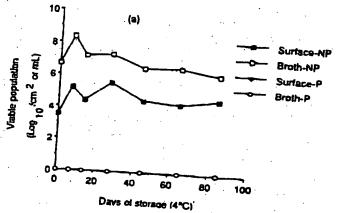
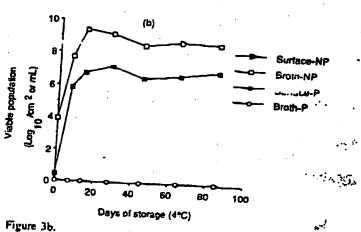


Figure 3a. (a) Total aerobic and (b) I'utal anaerobic microbial growth on the surface and in the broth of uninoculated precooked heef loin chunks. Data for pasteurized meat overlap, therefore. only one line is visible. (NP = nonpasteurized, P = pasteurized).



-27 Th يدينه ويتمالك المتناسب

essentially unchanged while microflors increased in fresh ground beef and liver, Johnson et al. (17) and Buchanan et al. (6) reported survival, but not growth, in fresh ground beef stored at 4°C. Glass and Doyle (14) inoculated (10<sup>s</sup> CFU/g) cooked beef roasts with a 5-strain mixture f L monocytogenes that included Scott A, 101M, and 103M. After 10 weeks, cooked beef roasts contained the same level of L monoi regenes that was present initially.

Aerobic and anaerobic indigenous microflora

Pasteurized beef loin chunks had lower (P < 0.05) aerobic and anaerobic microbial counts on the surface and in the broth compared to nonpasteurized chunks during 0 to 85 d of refrigerated storage (Fig. 3a and b). Pasteurization reduced the population of all indigenous microflora to undetectable levels (<30 CFU/ml or cm<sup>2</sup>).

Populations of total aerobic and anserobic microflors for nonpasteurized beef chunks increased (P < 0.05; surface and broth) after 7 a of storage. Another increase (P < 0.05) necurred between the 7 and 14th d of storage. After 14 d, the level of microflora on the surface and in the broth (ser bic and anaerobic) did not change (P > 0.05).

The indigenous microflors consisted of a mixture of bacteria from the following families: Lactobacillaceae (62%) Streptococcaceae (27%) and Enterobacteriaceae (11%). Identification of the exact species of lactobacilli present was not possible due to inconsistent results of specific carbohydrate fermentation reactions. Three species of the Enterobacteriaceae family were identified as Hafinia alvei, Escherichia blatta, and Citrohacter freundii and were 5.5, 3.3. and 2.2% of the total microflora, respectively. According to the confirmatory tests and the results of the Minitek kit. Streptococcus intermedius (also known as S. milleri) was the specific species from the family Streptococcaceue present in the meat.

The same microflora were also isolated from the strip I in prior to precooking. The mean aerobic and anaerobic plate counts of the uncooked strip loins were 5.67 and 5.58 log of cm2, respectively.

Indigenous Listeria spp.

Pasteurization completely eliminated indigenous Listeria spp. when a direct plating technique was used (Fig. 4). Statistically, there was no significant difference between the levels of Listeria spp. for nonpasteurized and pasteurized beef loin chunks. In addition, there was no change (P > 0.05) in population over time. From a practical viewpoint, the pasteurized meat would have been more desirable because it had a lower Listeria spp. population which reduced the chance of L. monocytogenes being present. In addition, the levels of Listeria spp. in the broth were increasing toward the end of the storage period (2.59 login/ ml. 85 d) and were similar to the population present after 7 d of storage (2.86 log<sub>in</sub>/ml).

When an enrichment procedure was used, Listeria spp. survived pasteurization in all precooked b ef chunks. All uninoculated meat samples were positive for Listeria spp. (data not sh wn). Preliminary data obtained using a 3-tube MPN procedure (7) indicated that Listeria spp were present at < 100 MPN/cm² or ml in pasteurized be...... chunks. L.

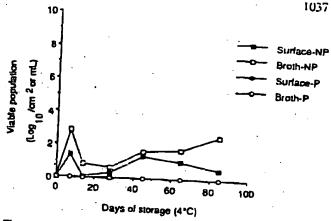


Figure 4. Gernerh of indigenous Listeria spp. on the surface and in the broth of uninoculated precooked beef loin chunks. Data for pasteurized meat overlup, therefore, unly one line is visible. (NP = nonpasteurized, P = pasteurized).

monocytogenes was present at levels of <10 CFU/g in 4.5% of the 50 beef roasts sampled (16).

The indigenous Listeria spp. were identified as Listeria welshimeri and Listeria ivanovii. The majority of the isolates (31 of 32) were L welshimeri. None of the isolates were identified as L. monocytogenes. L. welshimeri and L. innocua were isolated from one beef roast by Johnson et al. (18). In another study, L. monocytogenes was present in 82% of fresh meat samples containing multiple species of Listeria. L. innocua was detected in 55% of the fresh meat samples and 18% contained L. welshimeri (6). According to Farber et al. (13) when an average of 20 suspected colonies were used for confirmation for L. monocytogenes. 19 were L. innocua and 1 was L. monocylogenes.

#### CONCLUSIONS

Postpackaging pasteurization effectively eliminated three L. monocytogenes strains, indigenous Listeria spp., and microflora in precooked packaged beef chunks as measured by direct plating procedures. Hear-injured Listeria spp. and inoculated L. monocytogenes were recovered in enrichment broth from pasteurized samples. However, preliminary studies indicated that the levels were very low. Nonpasteurized beef loin chunks contained high levels of aerobic and anaerobic microflora after 14 d of refrigerated storage. L. monocytogenes survived in nonpasteurized chunks but did not increase in population throughout 85 d of refrigerated storage.

#### **ACKNOWLEDGMENT**

This work was partially funded by National Live Stock and Meat Buard and by the Agricultural Experiment Station of University of Illinois at Urhana-Champaign.

#### REFERENCES

- 1. Benson, H. J. 1982. Microbiological applications, W. C. Brown Co. Pub., Dubuque, IA.
- Bhaduri, S., P. W. Smith, S. A. Pulumbo, C. O. Turner-Jones, J. L. Smith, B. S. Marmer, R. L. Buchanan, L. L. Aika, and A. C. Williams. 1991. Thermal destruction of Listeria munucytogenes in liver sausage slurry. Fund Microbiol. n.75 78.

 Boyle, D. L., J. N. Sofos, and G. R. Schmidt. 1990. Thermal destruction of *Listeria monocytogenes* in a meat sturry and in ground beef. J. Food Sci. 55:327-329.

The state of the s

- Brackett, R. E. 1988. Presence and persistence of Listeria monocytogenes in food and water. Food Technol. 42(4):162-164.
- Buchanan, R. L. 1991. Private communication. Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Philadelphia, PA.
- Buchanan, R. L., H. G. Stahl, and D. L. Archer, 1988, Improved plating media for simplified quantitative detection of Listeria monucytogenes in foods. Food Microbiol. 4:269-275.
- Buchanan, R. L., H. G. Stahl, M. M. Bencivengo, and F. D. Corral. 1989. Comparison of lithium chloride-phenylethanol-moxalactum and modified Vogel-Juhnson agars for detection of *Listeria* spp. in retail-level meats, poultry. 2nd seafond, Appl. Environ. Microbiol. 55:599-603.
- Buchanan, R. L., J. L. Smith, H. G. Stahl, and D. L. Archer. 1988. Listeria methods development research at the Eastern Regional Research Center, U.S. Department of Agriculture. J. Assoc. Off. Anal. Chem. 71:651-654.
- Busch, S. V., and C. W. Donnelly. 1992. Development of a repairenrichment broth for resuscitation of heat-injured Listeria monocytogenes and Listeria innucua. Appl. Environ. Microbiol. 58:14-20.
- Cnoksey, K., B. P. Klein, and F. K. McKeith. 1993. Heating and texture profiles of precooked packaged pasteurized beef loin steaks. J. Food Sci. 58:5-8.20.
- Donnelly, C. W., and G. J. Baigent. 1986. Method for flow cytometric detection of *Listeria monocytogenes* in milk. Appl. Environ. Microbiol. 52:689-695.
- Farber, J. M., 1991. Listeria monocytogenes. J. Assoc. Off. Anal. Chem. 74:701-704.
- Farber, J. M., G. W. Sanders, and M. A. Johston. 1989. A survey of various foods for the presence of *Listeria* species, J. Food Prot. 52:456-458.

- Glass, K. A., and M. P. Doyle, 1989. Fate of Listerly monocytogenes in processed ment products during refrigerated storage. Appl. Environ. Microbiol. 55:1565-1569.
- Grau, F. H., and P. B. Vanderlinde, 1990. Growth of Listeria monocytogenes on vacuum-packaged beef. J. Food Prot. 53:739-741.
- Grau, F. H., and P. B. Vanderlinde, 1992. Occurrence, numbers, and growth of Listeria monocytogenes on some vacuum-packaged processed meats, J. Food Prot. 55:4-7.
- Johnson, J. L., M. P. Doyle, and R. G. Cassens, 1988. Survival of Listeria monocytogenes in ground beef, Int. J. Food Microbiol, 6:243-247.
- Johnson, J. L., M. P. Doyle, and R. G. Cassens. 1990. Listeria monocytogenes and other Listeria spp. in most and meat products; A review. J. Food Prot. 53:81-91.
- Kreig, N. R., and H. J. G. Holt. (ed.) 1984. Bergey's manual of systematic bacteriology. Williams and Wilkens, Baltimore, MD.
- Lachica, R. V. 1990. Selective plating medium for quantitative recovery of food-borne Listeria monocytogenes. Appl. Environ. Microbiol. 56:167-169.
- Lovett, J., and A. D. Hitchins, 1988. Listeria isolation: Revised method of analysis. Fed. Regist. 53:44148-44153.
- 22. Mackey, B. M., and N. Bratchell, 1989. The heat resistance of Listeria monocytogenes. Lett. Appl. Microbiol. 9:89-94.
- National Association of Meat Purveyors, 1988. The meat buyers guide, 1st ed. National Association of Meat Purveyors, McLean, VA.
- Shelef, L. A. 1989. Survival of Listeria monocytogenes in ground beef or liver during storage at 4 and 25°C. J. Food Prot. 52:379-383.
- Truscott, R. B., and W. B. McNab. 1988. Comparison of media and procedures for the isolation of Listeria monocytogenes from ground beef. J. Food Prot. 51:626-628.
- Webb, N. B., M. L. Speck, J. P. Hadden, A. R. Hovis, T. C. Wu, and N. S. Webb. 1990. Microbial concerns about procoaked convenience foods. 43rd Annual Reciprocal Meat Conference Proceedings, Chicago, IL. 43:97-101.

#### APPLIED TECHNOLOGY

#### Food preservation by combined methods

#### L. Leistner

Institute for Microbiology, Toxicology and Histology of the Federal Centre for Meat Research, D-8650 Kulmbach, Germany

Foods preserved by combined methods remain stable and safe even without refrigeration, and are high in sensory and nutritive properties due to the gentle processes applied. The concept is gaining ground in industrialized as well as in developing countries. Several topics will be discussed briefly: (1) water activity, (2) hurdle effect, (3) hurdle technology (4) shelf stable products, (5) intermediate moisture foods, and (6) perspectives.

Keywords: combined methods, hurdle technology, shelf stable products, intermediate moisture food, water activity.

#### 1 WATER ACTIVITY AND FOOD PRESERVATION

As is well known, the stability and safety of food does improve if the water activity  $(a_w)$  of the products decreases. Common methods for decreasing the  $a_w$  of foods are drying, addition of salt, sugar or polyols, and freezing. The  $a_w$  of foods influences the multiplication, metabolic activity, resistance and survival of the organisms present (Leistner *et al.*, 1981).

If we want to intelligently influence the  $a_w$  of foods, we have to know it. The  $a_w$  of foods may be calculated by employing equations (Chirife et al., 1980) or it is measured using suitable instruments. Several reliable instruments are today available, which measure  $a_w$  by applying different principles. We devised several years ago a simple hair hygrometer made by Lufft (Stuttgart, Germany) which is reasonably priced and works quite well, if handled with care (Rödel et al., 1975). Widely used are electric hygrometers made by Novasina or Rotronic (both Zürich, Switzerland), for measuring the  $a_w$  of foods (Rödel et al., 1979), these are more precise, but also more expensive. Recently our lab-

This is an introductory lecture to a symposium on 'Food Preservation by Combined Methods' held at the Annual Meeting of the Institute of Food Technologists, Dallas, Texas, 1-5 June, 1991.

Food Research International 0963-9969/92/\$05.00 © 1992 Canadian Institute of Food Science and Technology oratory has introduced a new instrument for the accurate and quick measurement of  $a_w$  in meats, which is based on the determination of the freezing point (Rödel et al., 1989). It is remarkable, that with this instrument made by Nagy (Filderstadt, Germany) an  $a_w$  measurement is done in about 15 min, and the same instrument can be employed for determining temperature, relative humidity, pH and redox potential, of course, by using different sensors. Such multipurpose instruments are appropriate for quality assurance in food processing.

The stability and safety of many foods is not based soley on  $a_w$ , but on the combined effects of several factors. Therefore, the  $a_w$  of foods should always be viewed in relation to other inherent factors, and this is the topic of this paper. The mode of action of the combined factors used in food preservation should be studied, since they could have an additive or even synergistic effect.

#### 2 HURDLE EFFECT AND FOOD STABILITY

The hurdle effect is an illustration of the fact that in most foods several factors (hurdles) contribute to stability and safety. This hurdle effect is of fundamental importance for the preservation of food, since the hurdles in a stable product control microbial spoilage and food poisoning as well as the desirable fermentation. There are many processes used for making foods stable and safe, e.g. heating, chilling, freezing, freeze drying, drying, curing, salting, sugar-addition, acidification, fermentation, smoking or oxygen removal. However, these many processes are based on relatively few parameters or hurdles, i.e. high temperature (F value), low temperature (F value), F value, F preservatives, and competitive flora. In some of the preservation methods mentioned, these parameters are of major importance, in others they are only secondary hurdles (Leistner et al., 1981).

We introduced the hurdle effect some years ago (Leistner, 1978), and it has since been modified and extended several times (Leistner, 1986a, 1987). The present concept is shown in Fig. 1, which gives eight examples. Example 1 illustrates the principle and represents a food which contains six hurdles (i.e. F, t,  $a_w$ , pH,  $E_h$ , and preservatives). The micro-

organisms present cannot overcome ('overjump') these hurdles, thus the food is microbiologically stable and safe. However, Example 1 is only a theoretical case, because all hurdles are of the same height, i.e. have the same intensity. A more likely situation is presented in Example 2, since the microbial stability of this product is based on hurdles of different intensity. In this product the main hurdles are the aw and preservatives, while other less important hurdles are storage temperature, pH and redox potential. These five hurdles are sufficient to inhibit the usual types and numbers of organisms associated with such a product. If there are only a few microorganisms present at the start (Example 3), then a few or low hurdles are sufficient for the stability of the product. The aseptic packaging of perishable foods is based on this principle. On the other hand, as in Example 4, if due to bad hygienic conditions too many und٤

us

sŗ

νi

isi

sυ

W.

ħ٤

If

ar

F.

de

fo

lr.

ra

in

ill-

sa

ta tie CE h٤ sy be E m in sp tb m in tic TC b€ fc 01

ca cc 15 pc c) lin sp fa (e to hi sa ni

al

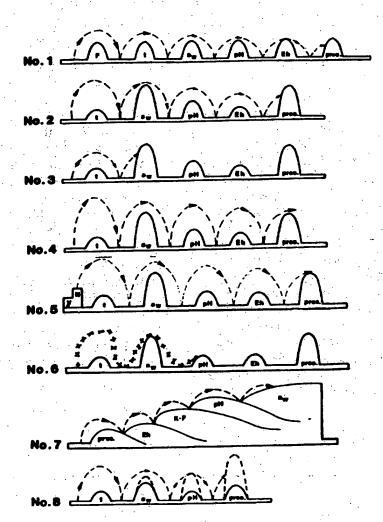


Fig. 1. Illustration of the hurdle effect, using eight examples. Symbols have the following meaning: F, heating: t, chilling:  $a_w$ , water activity; pH, acidification:  $E_b$ , redox potential; pres., preservatives: K-F, competitive flora; V, vitamins; N, nutrients.

ıp') ally. y a the / ore nce on the hile :railes ım-JCt. t at iles The

on

e 4,

un-

desirable organisms are initially present, even the usual hurdles inherent in a product cannot prevent spoilage or food poisoning.

Examples 5 is a food superior in nutrients and vitamins, which foster the growth of microorganisms ('trampoline effect'), and thus the hurdles in such products must be enhanced, otherwise they will be overcome. Example 6 illustrates the behaviour of sublethally damaged organisms in foods. If, for instance, bacterial spores in meat products are damaged sublethally by heat (as occurs in F-SSP, discussed later), then the vegetative cells derived from such spores lack vitality, and therefore are already inhibited by fewer or lower hurdles. In some foods, such as fermented sausages and raw hams, the microbial stability is achieved during processing by a sequence of hurdles. Example 7 illustrates the sequence of hurdles in fermented sausages, as will be discussed later.

Finally, Example 8 should illustrate an important phenomenon, which deserves particular attention in foods preserved by combined methods, because different hurdles in a food might not just have an additive effect on stability, but could act synergistically. A synergistic effect of hurdles is to be expected if the different factors (e.g. pH,  $a_{w}$ , E<sub>h</sub>, preservatives) have different targets within the microbial cell, and thus disturb the homoeostasis in several respects. This could make it difficult for spoilage or food poisoning organisms to overcome the lag-phase, and if multiplication is delayed the microorganisms eventually die. Therefore, employing different hurdles in the preservation of a particular food should be advantageous, because already with gentle hurdles microbial stability could be achieved. Certainly, the relationship between food preservation and the homeostasis of microorganisms deserves attention.

As Fig. 1 indicates, in fermented sausages we can distinguish five different hurdles which become active and fade out in a sequence (Leistner, 1985, 1986b). These hurdles effectively inhibit food poisoning organisms (Salmonella ssp., Listeria monocytogenes, Staphylococcus aureus, Clostridium botulinum) as well as other bacteria which might cause spoilage. On the other hand, this sequence of hurdles favours the selection of the desired competitive flora (especially lactic acid bacteria), which contribute to the stability of the products. An important hurdle in the early stage of the ripening process of salami is nitrite, added with curing salt, because nitrite inhibits the growth of salmonellae. Nitrite also inhibits some additional bacteria, while others

can grow and due to the multiplication of these bacteria the redox potential of the product decreases, and this in turn enhances the  $E_h$  hurdle, which inhibits aerobic rganisms and favours the selection of the competitive flora, primarily lactic acid bacteria. Their growth and metabolic activity cause acidification of the product and thus an increase of the pH hurdle. This is of particular importance for the microbial stability of quick ripened fermented sausages, which are not properly dried. The hurdles of nitrite,  $E_h$ , competitive flora and pH diminish with time, because in ripened salami the nitrite level and the count of lactic acid bacteria decrease, while the  $E_h$  and pH increase again. Only the  $a_w$  is strengthened with time, and this hurdle is mainly responsible for the stability of long ripened fermented sausages. Certainly, also in the processing and storage of some other foods, e.g. cheese, a sequence of hurdles is responsible for microbial stability, and it should be challenging to investigate this phenomenon in various foods.

With fermented sausages we can differentiate in Germany two groups; i.e. quick ripened products and slow ripened products. Quick ripened products amount to about 80% of the production and the slow ripened products to only 20%. In quick ripened products the a<sub>w</sub> is rather high, because they still contain much water, and therefore are less expensive. However, to compensate for this high a, a low pH in such products is necessary for microbial stability. On the other hand, slow ripened products, which are more expensive due to the long drying period, have a low  $a_w$ , and therefore these products can afford a rather high pH which makes them much more tasty. I mention these differences between quick and slow ripened salami, because they illustrate that the hurdles in a food are somehow interchangeable. Emphasis could be given to different hurdles to achieve stability, with the consequence that the products have different features related to their sensory properties and price.

#### 3 HURDLE TECHNOLOGY AND FOOD DESIGN

From the hurdle effect, the hurdle technology has been derived (Leistner, 1985, 1986a), since an intelligent combination of hurdles secures the microbial stability as well as the sensory nutritive, toxicological and economic properties of a food. The practical importance of hurdle technology for stable and safe foods has now been recognized by

the food industry. In food design as well as food control this principle is increasingly applied and has proved very successful.

Even the pet food industry has made novel and attractive products by applying hurdle technology. A stable pet food was formerly produced with an  $a_w$  of 0.85 and this needed addition of much propylene glycol which might have caused health implications in cats. But now based on hurdle technology pet foods are stable with an  $a_w$  of 0.94, and they are more healthy, tasty, and economic.

Hurdle technology is now widely used especially in food design, for making new products according to needs. For instance, if energy preservation is the goal, then energy consuming hurdles such as refrigeration are replaced by hurdles  $(a_w, pH)$  or  $E_h$ ) which don't demand energy and still ensure a stable and safe food (Leistner, 1978). Furthermore, it we want to reduce or replace preservatives, such as nitrite in meats, we could emphasize the other hurdles in a food, e.g.  $a_w$ , pH, refrigeration, or competitive flora, which would stabilize the products (Leistner et al., 1980).

Food control could be based on the physical and chemical measurement of hurdles in a food and computer evalution of the results. This approach could give faster and sometimes more reliable information on the stability and safety of foods than a microbiological investigation. Hurdle technology used for food control may be regarded as a precursor of predictive microbiology.

Hurdle technology is by no means a new process, as has been pointed out by Chirife et al. (1991) in their study on mummification in ancient Egypt. In the opinion of these authors the embalmed mummies contained (at least) three hurdles, namely reduced  $a_w$  (0.72), increased pH (10.6) and preservatives (spices, aromatic plants). Therefore, the application of combined methods used for preservation has indeed a long history.

#### 4 SHELF STABLE PRODUCTS (SSP) STORABLE WITHOUT REFRIGERATION

The term SPP was introduced by our laboratories (Leistner & Rödel, 1979) for high moisture meats ( $a_w > 0.90$ ), which may be stored for weeks or months without refrigeration, in spite of a mild heat treatment. We predicted (Leistner *et al.*, 1979) that SSP would gain importance. Fox & Loncin (1982) emphasized that in heated foods

which contain only viable spores of bacilli and clostridia the microbial stability could be more easily achieved by certain hurdles, than in products where a large range of microorganisms is present.

Stability without refrigeration is an important feature for foods in developing as well as industrialized countries. In developing countries refrigeration is not readily available and in industrialized countries foods which need no refrigeration save costs by saving energy during distribution and storage. Furthermore, mild heat treatment (70-110°C core temperature) is beneficial, because it fosters the sensory and nutritional properties of the products. However, the heat process must be sufficient to inactivate all but sporulated bacteria. Since the containers are sealed, a recontamination of foods after heating is avoided. SSP still contain viable spores of bacteria, but the growth of surviving bacilli and clostridia is inhibited by a sufficient decrease of  $a_w$ , pH, and  $E_h$ . A low redox potential favours clostridia, on the other hand some bacilli are more a<sub>w</sub>-tolerant than clostridia but can be inhibited by a low  $E_{\rm h}$ . Therefore a low redox potential overall contributes to the microbial stability of SSP meats (Leistner et al., 1980). For industrialized countries production of SSP is more attractive than intermediate moisture foods, because of the required a<sub>w</sub> for SSP is not as low, and thus less humectants and/or less drying of the products are necessary.

Depending on the hurdles which are most important for the stability of a particular product group, we distinguish today between F-SSP, a, SSP, pH-SSP and Combi-SSP; minor hurdles are also active in these products. The primary reason for stability of F-SSP is the inactivation or sublethal damage of bacterial spores, for aw the reduction of aw, for pH-SSP an increased acidity, and in Combi-SSP several hurdles are balanced out. Traditional SSP meats (both a<sub>w</sub>-SSP and pH-SSP) have been on the market for many years, the F-SSP were introduced about 10 years ago, and Combi-SSP are still under development, Hitherto the SPP concept has been mainly applied for meat products, however, certainly it could be useful for other foods too.

SSP are quite sophisticated products, which need reliable control of important critical points during manufacture, therefore, their processes are best defined using the HACCP concept. During processing the temperature and time as well as pH and  $a_{\rm w}$  should be strictly controlled, a micro-

.

1 6 6

1 1

•

1 1 1

1 1 :

and nore prois is

tant dusfrigrialtion tion tion nent nuse s of

t be

ria.

tion

tain suruffidox and idia low

80).
P is ods, ow, the

luct

a<sub>w</sub>
are

son

subluc-

im-

and out. SP): F-and

erto neat for

ints are ring l as biological investigation of the products based on suggested guidelines would provide additional information (Hechelmann et al., 1991).

#### 4.1 F-SSP

During the last decade German meat processors have introduced a new line of mildly heated meat products, which are sold in huge quantities by discount chains without refrigeration. These products are autoclaved sausages in casings, called F-SSP (Leistner, 1985). The products are given only relatively mild heat treatment (F value 0-4), which inactivates all vegetative microorganisms and sublethally damages spores. Bacteria deriving from such spores have a diminished vitality, and therefore are already inhibited by aw and pH values that are not detrimental to the sensory properties of the products. A low  $E_h$  contributes to stability (Leistner et al., 1980). The four hurdles which are most important for the stability and safely of F-SSP have been called the 'magic square' (Leistner, 1986a, 1987), and in some products (Brühwurst) nitrite is also a hurdle.

F-SSP consist of liver, blood and Bologna-type (Brühwurst) sausages (100-500 g), filled in artificial PVDC-casing (30-45 mm diameter), impermeable to water vapour and to air, and closed by clips. These sausages are autoclaved for 20-40 min at 103-108°C under stringently controlled counter pressure (1.8-2.0 bar during heating, 2.0-2.2 bar during chilling). The autoclaved sausages have a shelf-life of at least 6 weeks without refrigeration. Strangely enough the F-SSP might even become sterile during storage. This is due to the fact that bacterial spores are able to germinate under less favourable conditions than where the vegetative cells of bacilli and clostridia are able to multiply. Therefore, during storage of the products some of the viable spores germinate, but the vegetative cells deriving from these spores die. Thus the spore count actually goes down during storage.

Of course, this will only happen if the products are microbiologically stable due to the following hurdles: the sausages must be heated to F values higher than 0.4, and if the initial spore count in the products was low (due to the use of spice extracts instead of natural spices), only relatively few bacterial spores will survive this heat treatment. The  $a_{\rm w}$  of F-SSP must be lower than 0.97 in Bologna-type sausages and lower than 0.96 in liver and blood sausages. The higher  $a_{\rm w}$  in Bologna-type sausages (Brühwurst) is possible, because

nitrite is still active in these products, whereas the a, must be lower in liver and blood sausages. because in these products the nitrite is inactivated by the high iron content. The  $E_h$  sh uld be low in order to inhibit a<sub>w</sub>-tolerant bacilli, and the air tight casings secure a low  $E_h$ . The pH of F-SSP should be lower than 6.5, but this is only critical in blood sausages, because the other products have a pH close to 6.0. Finally, for F-SSP casings are more advisable than cans (Hechelmann et al., 1985), because during chilling of the cans after autoclaving, some water condensation may occur inside the lid, and if drops of water fall back on the surface of the sausage mix, locally the a increases and thus growth of clostridia may start in this portion of the product. If autoclaved sausages fill the casings tightly, water condensation inside the container cannot occur, and therefore F-SSP in casings are more stable than in cans with headspace.

F-SSP have not caused botulism or severe spoilage problems during the decade they have been on the market. The obligatory guidelines for the manufacture of safe and stable F-SSP have been investigated and reported by Hechelmann & Leistner (1984).

#### 4.2 a\_-SSP

The term a.-SSP was chosen for products stabilized mainly by a,, although other hurdles are important for their stability too (Leistner, 1985). The first experiments into a.-SSP were done by Leistner & Karan-Djurdjić (1970). However, for a long time there have been already traditional  $a_{w}$ -SSP meats on the market, such as Italian Mortadella and German Brühdauerwurst, which have been produced empirically with an a close to 0.95, but none of the manufacturers measured the  $a_w$  f their products or even recognized the significance of water activity. In Italian Mortadella the reduction of the  $a_w$  is achieved mainly by the formulation of the sausage and some drying during heating of the product. Whereas German Brühdauerwurst acquires the desired a primarily by drying of the finished product. Due to the  $a_w$  adjustment both product groups may be stored without refrigeration. Since the lipases are inactivated by heat in a.-SSP meats, they are stable longer than fermented sausages. According to Wirth (1979), fermented sausages can be stored 15 months and German Brühdauerwurst even 18 months without much sensory deterioration.

The processing and stability of both groups of traditional aw-SSP meats have been studied in ur laboratories (Leistner et al., 1979). For stable and safe meat products of the a<sub>w</sub>-SSP type, the following guidelines (Leistner, 1987) must be observed: a. SSP should be heated to an internal temperature of at least 75°C in a sealed container, preferably casings. The water activity of  $a_w$ -SSP must be adjusted to or below 0.95. Thus, a lower  $a_w$  is more essential than for F-SSP, because with the milder heat treatment of a<sub>w</sub>-SSP the bacterial spores are damaged less than in F-SSP. The  $E_{\rm h}$  of the product should be low, because a reduced redox potential contributes to the growth inhibition of  $a_w$ -tolerant bacilli. The growth of moulds on  $a_w$ -SSP could be troublesome, because the surface  $a_{\rm w}$  of these products (since the casings are penetrated by water vapour) corresponds to the a. of the interior. Mould growth on the surface of a<sub>w</sub>-SSP meats could be avoided by smoke or potassium sorbate treatment, or by vacuum packaging of the products. Hechelmann et al. (1991) recommended repasteurization of the vacuum packaged  $a_w$ -SSP for 45 min at 85°C. By this process not only moulds are inactivated but also other organisms, including lactic acid bacteria, which might grow on the vacuum packaged meats during storage. Repasteurized vacuum packaged  $a_w$ -SSP have a superior shelf-life.

#### 4.3 pH-SSP

It is well known that pasteurized fruit and vegetable preserves with a pH <4.5 are bacteriologically stable and safe, in spite of only mild heat treatment. In such products vegetative microorganisms are inactivated by heat, and the multiplication of surviving bacilli and clostridia is inhibited by the low pH. Such foods could be called pH-SSP (Leistner, 1985). Since bacterial spores are able to germinate at lower pH levels than vegetative bacilli and clostridia are able to multiply, in pH-SSP, as in F-SSP and  $a_w$ -SSP, the number of spores tends to decrease during storage. On the other hand, while the heat resistance of bacteria and their spores is enhanced with decreasing a<sub>w</sub>, it is diminished with decreasing pH. Thus pH-SSP need less heat treatment for the inactivation of microorganisms than do  $a_{\mathbf{w}}$ -SSP.

Meat products of the pH-SSP type are brawns and in this jelly sausages are adjusted to an appropriate pH by the addition of acetic acid. Such products are, for example, composed of a brine

(pH 4-8) made of water, gelatine, salt, sugar, agaragar (1%), and spice, and a solid phase, made of Frankfurter-type sausage in cubes with an  $a_w$  of 0-98. Both components are mixed (2 parts brine: 3 parts meat), filled in casings and heated to an internal temperature of at least 72°C but not higher than 80°C. If the product is in equilibrium, it should have a final pH below 5-2, and then it is storable for 6 days at 30°C without refrigeration (Hechelmann et al., 1991).

#### 4.4 Combi-SSP

Some SSP are stabilized by several hurdles which have to be well balanced with each other. Our experimental work suggests that even small enhancements of the individual hurdles in a food in summation have a definite effect on the microbial stability of a product. Figure 2 illustrates this phenomenon. For instance, for the stability and safety of meat products it is of significance whether the F value is 0.3 or 0.4, the  $a_w$  is 0.975 or 0.970, the pH is 6.5 or 6.3, and the  $E_h$  value is somewhat higher or lower. Every small improvement or reinforcement of a hurdle brings some weight to the balance, and the sum of these weights determines whether a food is microbiologically unstable, uncertain, or stable (Fig. 2). In other words, all little steps in the direction of stability will finally decide whether or not the balance swings from an unstable into a stable state of a product. The quantification of these influences on the microbial stability of foods is an important research area of food designs. In this endeavour technologists and microbiologists must work together. The technologist must determine which additives are suitable for the enhancement of hurdles in foods by taking technological, toxi-

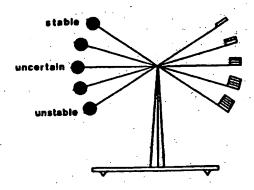


Fig. 2. The balance should illustrate that even small enhancements of different hurdles could bring about in summation a substantial improvement of the microbial stability of a food.

s t t c t v c s l F F a 4

C

iı

r.

t

C

T.

T.

F

1

V

ŀ

T.

r

t.

V

E

iı

Ċ

a

n

5

F

(

ť.

T s ti s N

k s of of ne: in-her it is ion

ich )ur enin pial his and nce or is veme

ese

og-

In of the ble ese an his ust ine ent

n a

od.

cological, sensory, nutritive, and legal limitations into consider ion. The microbiologist must determine which intensity of factors or hurdles in a particular food are needed for the desired microbiological stability, and his concept has to be challenged by inoculation studies using relevant microorganisms in feasible numbers. Predictive microbiology could be useful in this respect too.

As an example of a Combi-SSP the Gelderse Rookworst of the Netherlands could be mentioned. This is a Bologna-type sausage (Brühwurst) in which the pH by the addition of glucono-deltalactone is adjusted to 5.4-5.6. This product is microbiologically stable for several weeks without refrigeration, if vacuum packaged in a pouch and then pasteurized at 80°C. This treatment inactivates vegetative organisms in and on the sausages. Bacterial spores are apparently not of much concern in this product, since their population decreases during the heating process and the surviving spores are inhibited by the low pH. If the product is manufactured with a somewhat higher pH, the sensory properties definitely improve, however, then the  $a_{\rm w}$  of the product has to be lowered in order to obtain the desired stability.

We have followed this line in our product design of Bologna-type sausages as Combi-SSP. Different types of Brühwurst (wieners, bockwurst, fleischwurst, fleischkäse, fleischkäse in slices) were developed which proved stable and safe during 6 days of storage at 30°C. The initial spore load should be low, and these products are heated to a core temperature >72°C, and are adjusted to an  $a_w$  and pH of 0.965 and <5.8, respectively. The products are re-pasteurized after vacuum packaging for 45-60 min (depending on the diameter of the products) at 82-85°C (Hechelmann et al., 1991). Combi-SSP offer many opportunities, however, they require strict process control following the HACCP concept.

#### 5 NOVEL AND TRADITIONAL INTERMEDIATE MOISTURE FOODS BASED ON MEAT

The intermediate moisture foods (IMF) are stabilized by  $a_{\rm w}$  in the range of 0.90-0.60, although additional hurdles, such as heating, preservatives, pH and  $E_{\rm h}$  might be important too. Many traditional and some novel IMF are known. Such foods need no refrigeration during storage.

#### 5.1 Novel IMF

An example of this product gr up in the meat field is mini-salami. This product is liked by the consumers as a snack and it is produced in large quantities in Germany, also for export. Minisalami is based on hurdle technology and is produced either as fermented sausage  $(a_w < 0.82)$  or as dryed Bologna-type sausage  $(a_w < 0.85)$ . In the packaging of mini-salami a modified atmosphere is used in order to delay rancidity and to avoid the growth of moulds (Tändler & Rödel, 1983). As the example of mini-salami demonstrates, a modified atmosphere could be another hurdle which contributes to stability, especially if carbon dioxide is used.

#### 5.2 Traditional IMF

In different regions of the world, traditional IMF based on meat are known. This is especially true of Asia (e.g. tsusou-gan, njorsou-gan, sou-song of China, or dengdeng giling of Indonesia) as well as for Africa (e.g. biltong, khundi, quanta, pasterma, klich, iamkila). Some IMF meats are also known in America (e.g. charque, carne de sol, beef jerky). The IMF based on meat are nutritious and palatable, and are much liked by the consumers.

In such products hurdle technology is empirically applied, and they are easy to prepare and to store, because only simple equipment is needed, and neither expensive packaging nor refrigeration are required. Furthermore, common humectants (salt and sugar) are employed, and thus no 'chemical over-loading' of these foods results.

Recently, the traditional IMF based on meat have been reviewed (Leistner, 1990, 1991), and thus in this contribution a few remarks should suffice. It is obvious that a thorough study of traditional IMF using up-to-date methodology would be of benefit to developing countries. However, also for industrialized countries such studies are rewarding, because traditional products are an abundant source of innovative ideas which could be used in food design. For instance, we learned from Chinese sausage (lup cheong) that a sausage could be preserved in the raw state even without fermentation, or we realized that in charque of Brazil a fermentation takes place even at an  $a_w < 0.90$ , if halophilic pedicocci are involved. Heat inactivation of most pathogenic bacteria, including staphylococci, is achieved in some Chinese IMF meats by just applying 50°C for several hours. Another interesting aspect of traditional IMF meats is the bacteriocidal effect of Maillard products towards food poisoning organisms, because if these recontaminate the product after heating, and drying they don't survive long. Appar ntly the growth inhibition of xerotolerant moulds on unpackaged Chinese dried IMF meats with an  $a_{\mathbf{w}}$  of 0.69 is also supported by Maillard reaction products, which therefore probably are important hurdles for traditional IMF.

#### 6 CONCLUSIONS AND PERSPECTIVES

Food preservation based on combined methods is applicable for the improvement of traditional products as well as the design of novel foods. Combined methods secure stable and safe foods in spite of a gentle preservation, and thus result in products with high sensory and nutritive properties. Research in combined processes has brought about admirable results in Latin America within the CYTED-D project. Also combined methods for food preservation are currently studied in Europe within a project of the FLAIR-PROGRAM, and eleven countries participate in this project.

Several concepts for improvement of the safety, stability and quality of foods have emerged in recent years and are pursued. Now, taking into consideration Good Manufacturing Practice (i.e. a better defined GMP), Hurdle Technology, the HACCP Concept and Predictive Microbiology, an overall strategy for better foods should be derived, which is applicable in industry as well as in small and medium size enterprises, if possible world-wide.

#### REFERENCES

Chirife, J., Ferro Foután, C. & Benmergui, E. A. (1980). The prediction of water activity in aqueous solutions in connection with intermediate moisture foods. IV. a<sub>w</sub> prediction in aqueous non electrolyte solutions. J. Food Technol., 15, 59.

Chirife, J., Favetto, G., Ballesteros, S. & Kitic, D. (1991). Mummification in ancient Egypt: an old example of tissue preservation by hurdle technology. *Lebensm.-Wiss. u.-Technol.*, 24, 9,

Fox, M. & Loncin, M. (1982). Investigation into the microbiological stability of water-rich foods processed by a combination of methods. Lebensm.-Wiss. u.-Technol., 15, 321.

Hechelmann, H. & Leistner, L. (1984). Mikrobiologische Stabilität autoklavierter Darmware. Mitteilungsblatt Bundesanst. Fleischforsch., Kulmbach, No. 84, 5894.

Hechelmann, H., Leistner, L. & Albertz, R. (1985). Ungleichmäßiger aw-Wert als Ursache für mangelhaste Stabilität

v n F-SSP. Jahresbericht Bundesanst. Fleischforsch., Kulmbach, C27.

Hechelmann, H., Kaspr wiak, R., Reil, S., Bergmann, A. & Leistner, L. (1991). Stabile Fleischerzeugnisse mit Frischprodukt—Charakter für olie Truppe. BMVg FBWM 91-11-DOK/BW/0050/82.

Leistner, L. (1978). Hurdle effect and energy saving. In Food Quality and Nutrition, ed. W. K. Downey. Applied Science

Publishers, London, p. 553.

Leistner, L. (1985). Hurdle technology applied to meat products of the shelf stable product and intermediate moisture food types. In *Properties of Water in Foods in Relation to Quality and Stability*, ed. D. Simatos & J. L. Multon. Martinus Nijhoff Publishers, Dordrecht, p. 309.

Leistner, L. (1986a). Hürden-Technologie für die Hestellungstabiler Fleischerzeugnisse. Fleischwirtschaft, 66, 10.

Leistner, L. (1986b) Allgemeines über Rohwurst. Fleisch-

wirtschaft, 66, 290.

Leistner, L. (1987). Shelf-stable products and intermediate moisture foods based on meat. In Water Activity: Theory and Applications to Food, ed. L. B. Rockland & L. R. Beuchat. Marcel Dekker, New York, Basel, p. 295.

Leistner, L. (1990). Fermented and intermediate moisture products. Proc. 36th Int. Congress Meat Science and Technology. Vol. III, held Aug. 27-Sept. 1, 1990, Havana, Cuba, p. 842. Leistner, L. (1991). Fermented and intermediate-moisture

meat products. Outlook on Agriculture, 20, 113.

Leistner, L. & Karan-Djurdjic, S. (1970). Beeinflussung der Stabilität von Fleischkonserven durch Steuerung der Wasseraktivität. Fleischwirtschaft, 50, 1547.

Leistner, L. & Rödel, W. (1979). Microbiology of intermediate moisture foods. In Food Microbiology and Technology, ed.
B. Jarvis, J. H. B. Christian & H. D. Michener. Medicina Viva Servizio Congressi, Parma, p. 35.

Leistner, L., Wirth, F. & Vuković, I. (1979). SSP (Shelf Stable Products)—Fleischerzeugnisse mit Zukunft. Fleischwirt-

schaft, 59, 1313.
Leistner, L., Vukovic, I. & Dresel, J. (1980). SSP: meat products with minimal nitrite addition, storable without refrigeration. Proc. 26th Europ. Meeting Meat Res. Workers, Vol II., held Aug. 31-Sept. 5, 1980, Colorado Springs, p. 230.

Leistner, L., Rodel, W. & Krispien, K. (1981). Microbiology of meat and meat products in high- and intermediate-moisture ranges. In Water Activity: Influences on Food Quality, ed. L. B. Rockland & G. F. Stewart. Academic Press, New York, p. 855.

Rodel, W., Ponert, H. & Leistner, L. (1975). Verbesserter a.-Wert-Messer zur Bestimmung der Wasseraktivität (a.-Wert) von Fleisch und Fleischwaren. Fleischwirtschaft, 55,

Rödel, W., Krispien, K. & Leistner, L. (1979). Messung der Wasseraktivität (a<sub>w</sub>-Wert) von Fleisch und Fleischerzeugnissen. Fleischwirtschaft, 59, 831.

Rödel, W., Scheuer, R. & Wagner, H. (1989). Neues Verfahren zur Bestimmung der Wasseraktivität bei Fleischerzeugnissen. Fleischwirtschaft, 69, 1396.

Tändler, K. & Rödel, W. (1983). Herstellung und Haltbarkeit von dünnkalibrigen Dauerwürsten. II Haltbarkeit. Fleishwirtschaft, 63, 150.

Wirth, F. (1979). Vergleich roher und erhitzter Fleischerzeugnisse bei langer Lagerung. Proc. 25th Europ. Meeting Meat Res. Workers, Vol II, held Aug. 27-31, 1979, Budapest, Hungary, p. 587.

NOTICE: This material may be protected by copyright law (Title 17 U.S. Code)

## Survival of *Listeria monocytogenes* in Postpasteurized Precooked Beef Roasts

MARGARET D. HARDIN', SCOTT E. WILLIAMS", and MARK A. HARRIBON'

Department of Animal Science and Department of Food Science and Technology, University of Georgia, Athens, Georgia 30602

(Received for publication October 2, 1992)

#### ABSTRACT

The potential for Listeria monocytogenes to survive various times and temperatures of postposteurization in precooked beef roasts was investigated. Precooked eye of round roasts were inoculated with 10° cells of L monocytegenes per package grior to packaging in cook in bags and postpasteurization. Four groups of roasts (n = 54) each containing 27 uninoculated and 27 inoculated reasts were allotted to four pasteurization treatments consisting of two different exposure temperatures (91°C, 96°C) and two different dwell times (3 min, 5 min). Equal numbers of inoculated and uninoculated roasts from each treatment were then stored at 4 and 10°C. Triplicate samples of inoculated and uninoculated roasts were sampled on day 1, 4, 2, and 12 for product stored at 10°C and 1, 8, 14, 28, and 56 d for product stored at 4°C. Servivors were encountered for every treatment employed. The lethelity of the treatment was directly related to an increase in dwell time and postpesteurization temperature. Treatment 4 (96°C, 5 min) was found to decrease the L. monocytogener population the greatest (p < 0.05) and also maintained a lower (p < 0.05) count from its initial inoculum level during storage at both 4 and 10°C.

The use of heat for the inactivation of microorganisms is fundamental in food preservation (20). Any process that uses heat for inactivation of thermotolerant microorganisms, such as Listeria monocytogenes, becomes a critical control point in that food production system. The increased use of new packaging and process technology, such as cook-in systems, for ready-to-eat meats in foodservice, coupled with consumer, industry, and government concerns with food safety, increases the need for research in this area.

Cook-in systems have been shown to increase the yield and shelf life, as well as provide a more effective means of packaging meat products (19). The cook-in-strip process allows for the creation of innovative new products by portion controlling and by allowing for the addition of spices, flavorings, and other ingredients to a precooked product. However, the rehandling, reprocessing, and repackaging of the cook-instrip product makes this product particularly susceptible to recontamination by potentially hazardous microorganisms, such as L. monocytogenes.

L monocytogenes has been documented as the causative agent in cases of foodborne illness involving dairy and poultry products (21). Few cases of listeriosis associated with

red meats have been documented. However, the widespread distribution of L. monocytogenes in nature and its association with domestic livestock (18,22) makes the presence of the organism during the processing of meat and meat products unavoidable (1,14). While the presence of Listeria spp. in fresh meats and meat products is welldocumented (10,14,15,18), evidence for growth of L. monocytogenes in cooked beef is less substantial (3,12).

The current zero tolerance level for L monocytogenes established by U.S. Department of Agriculture/Food Safety and Inspection Service (USDA-FSIS) (7) in cooked readyto-eat meat products increases the need to reduce the incidence of L. monocytogenes in orecooked meats Research has shown that postcooking pasteurization of a product surface at fairly high temperatures (71-96°C) for short periods of time (30 s-5 min) may reduce the microbial load, thereby extending product shelf life (6) Bently (2) found that treatment at 96°C (205°F) for 10 min was more efficient than treatment at 96°C (205°F) for either 3 or 5 min in reducing total acrobic, anacrobic, and lactobacilli counts on roast beef products. While counts for untreated (no postpasteurization) roasts reached 10° after 8 weeks of storage (4°C), treated rossts (96°C, 10 min) maintained significantly lower counts of 102-102, within 1 log of initial levels (109) for acrobic, anacrobic, and lactobacilli. Cooksey (4) found postpasteurization of beef chunks at 82°C for 16 min significantly reduced levels of L. monocytogenes by 10,000-fold on the surface and 1,000,000-fold in the broth from inoculum levels of 10° CFU/z. The inhibitory effect of postpasteurization has been shown, in shelf-life studies, to vary depending on the times and temperatures used in the postpasteurization process (2,6).

Differences in survival of microorganisms with varying postpasteurization treatments points out a need for more specific guidelines to define this critical control point. Currently, there are no specific inspection guidelines to insure the consistency of postpasteurization between plants. Therefore, the objectives of this research were to determine the fate of L. monocytogenes in precooked beef roasts subjected to various postpackaging pasteurization treatments and to evaluate the shelf-life stability of inoculated, postpasteurized beef roasts.

#### MATERIALS AND METHODS

Product preparation

One hundred and twenty-four, USDA Choice, vacuum-packaged beef eye of round roasts (IMPS No. 171C) were purchased and shipped to the University of Georgia Meats Laboratory. All product arrived frozen and was held at -26°C until ready for use. Eye of rounds (weighing approximately 1750 g) were thawed in groups of 31, removed from their barrier bag, and repackaged in 55.9 x 27.9 cm (22 x 11 in) CN530 cook-in bags (Cryovac, Duncan, SC). The roasts were steam cooked in a smokehouse (Alkar, Lodi, WI) at 63°C for 2 h, 74°C for 1 h, and at 82°C for 1.5-2 h until they reached an internal temperature of 63°C. The roasts were cold shower chilled for approximately 15 min to 4°C and placed in a cooler (4°C) overnight. The following day, roasts were stripped of packaging material and cut in half. For 27 of the roasts, one-half of each roast was weighed for later purge determination, and repackaged in a CN530 cook-in bag before postpasteurization. The remaining half was inoculated before repackaging and postpasteurization. An additional eight halves were rebagged to be used for monitoring the temperature of the roasts during postpasteurization.

Time and temperature parameters were selected based on previous research (2). Bently (2) postpasteurized whole top rounds at 205°F (96°C) for 3, 5, and 10 min. However, for the present study, using half eye of rounds, the lower dwell times (3 and 5 min) and an additional lower temperature (91°C) were selected.

Inoculum preparation

Four strains of L. monocytogenes (Scott A, LCDC, V7. and Brie) were maintained in Trypticase soy broth at 4°C. In preparation for inoculation onto half eye of round roasts, Trypticase soy broth cultures of each strain were grown for 24 h at 35°C. Each strain was mixed together before being pelleted by centrifugation (10 min, 1,500 rpm). The cells were washed twice by centrifugation in 50 ml of phosphate buffer and resuspended in 10 ml phosphate buffer to give an approximate population of 1 x 10° CFU/ml of inoculian.

#### Inoculation and preparation of product

Each half eye of round to be inoculated was aseptically transferred to individually labeled CN530 bags. A 10-ml aliquot of the mixed strain inoculum, containing approximately 10° CFU/ml, was distributed dropwise over the product surface and thoroughly spread inside the bag by massaging for 2 min. The inoculated roasts were vacuum packaged using a tabletop Multivac (A300/16) vacuum-packaging machine. All roasts were chilled overnight in a 4°C cooler and held until the postpasteurization treatment was performed (within 24 h of inoculation).

#### Heat treatment of product

Each treatment, containing 27 inoculated, 27 uninoculated, and 8 temperature monitoring roasts was performed on a different day. On the day of postpasteurization, the vacuum-packaged roasts were removed from the cooler (4°C) and immersed, in batches of 14-16 roasts each, into a hot water bath with forced air circulation. Heat-tolerant plastic tubing was run from a tabletop air jet in the laboratory into a hot water shrink tank to provide the air for circulation of the water bath. The temperature of the water bath and dwell time varied according to treatment (TRT): TRT 1 = 91°C for 3 min; TRT 2 = 91°C for 5 min; TRT 3 = 96°C for 3 min; TRT 4 = 96°C for 5 min. Following heat treatment, roasts were transferred immediately to an ice bath (0°C) and cooled to 4°C (approximately 15 min). Thirty roasts (15 inoculated and 15 uninoculated) from each treatment were transferred to a 4°C cooler and 24 (12 inoculated and 12 uninoculated) rossts were transferred to a 10°C incubator for shelf-life evaluation. Triplicate samples of inoculated

(n = 3) and uninoculated (a = 3) roasts were pulled at 1, 8, 14, 28, and 56 d from 4°C storage and at 1, 4, 8, and 12 d from 10°C storage.

To monitor the temperature of the roast halves during postpasteurization, eight uninoculated roast halves (2 per batch) were used as controls. For these roasts, Type T constantine/copper thermocouple wire was inserted through brass stuffing boxes for plastic pouches (Ecklund/Harrison Technology, Cape Coral, FL). The thermocouples were placed on the product surface and 3 sun beneath the surface of the product. An additional thermocouple was placed in the water for monitoring in order to aid in controlling the water bath temperature. Temperatures were recorded on a Molytek (New Hartford, CT) Portable 32 Channel Recorder/Dataloguer.

Sampling and enumeration of product

At the predetermined storage times, triplicate inoculated rossts were tested for the presence of L. monocytogenes. Each bug was swabbed with 70% alcohol and opened aseptically with a flame sterilized knife. The roast was rinsed in the cook-in bag, with 100 ml of phosphate buffer and massaged for 2 min to insure maximum recovery. Prior to this project recovery studies with L. monocytogenes found a 2 min message allowed for maximum recovery of inoculum. Isolation and identification of L. monocytogenes were done using the media described by Lee and McClain (11). The phosphate rinse was further diluted as necessary for the direct plating enumeration of L. monocytogenes on duplicate spread plates of Listeria selective agar/Oxford formulation (LSA-OX, Oxoid). Plates were incubated at 35°C for 24 h. Typical colonies demonstrating esculin hydrolysis in this media were counted as presumptive Listeria. In the event that Listeria populations were below the detection level of the plating procedure, enrichment procedures were followed by transferring a 1-ml sample of the original rime solution into Listeria selective enrichment/University of Vermont medium (UVM) formulation broth (LSB-UVM, Oxoid). After incobation at 35°C for 24 h, tubes exhibiting growth were transferred to Fraser Broth (8) for presumptive detection of Listeria. Otheres were gently vortexed and a 0.1-ml aliquot was transferred to Fraser broth for incubation at 35°C for 24 h. A visual blackening of the medium due to esculin hydrolysis was considered presumptively positive for Listeria spp. For confirmation of L. monocytogenes, Q.1 ml of the Fraser culture was spread onto LSA-OX and incubated at 35°C for 24 h. Typical colonies were then transferred into GI motility medium (Difce) and incubated at 25°C for 24-48 h. Confirmation of L. monocytogenes was based on the umbrella motility exhibited by the organism in this medium. Randomly selected colonies of Listeria spp. were grown on Trypticase soy agar with yeast extract and subjected to additional testing for biochemical confirmation of L. monocytegenes. The following tests were used for confirmation of these isolates: Gram stain, blood star hemolysis, catalase, oxidase, and Micro-ID Listeria test strip (Organon Teknika Corp., Durham, NC).

Uninoculated product was rinsed and plated on duplicate plates of LSA-OX for direct counts of Listeria spp. and onto two sets of duplicate plates of plate count agar for direct counts of mesophilic and psychrotrophic organisms. A 1-ml aliquot was also transferred to LSE-UVM for recovery of low numbers and/or injured organisms. Tubes and LSA-OX plates and one set of plate count agar plates were incubated at 35°C for 24 h. Colonies which developed on the plates were counted for determination of Listeria and mesophiles. Representative colonies from all Listeria-positive samples received biochemical testing after motility was confirmed. The plates for psychrotrophic organisms were incubated for 14 d at 4°C and colonies that developed were counted.

Statistical analysis

A general linear model (17) was used to evaluate the fixed effects of dwell time and temperature as well as storage time and

storage temperature. All microbial counts were converted to I g<sub>10</sub> CFU before analysis. Determination of significance in the analysis of treatment ffects used least significant means separated by a simple T test.

#### RESULTS

#### Inoculated product:

Growth and survival of L monocytogenes inoculated onto vacuum-packaged roast beef, postpasteurized at four different treatment levels and stored at 4 and 10°C is shown in Tables 1 and 2. Because the initial inoculum varied for each treatment, the rate of growth as a difference from inoculum level is illustrated in these tables. A tendency is noted (Table 1) for greater lethality to L monocytogenes with longer dwell time and increased temperature treatment. Treatment 4 (Tables 1 and 2) showed the greatest initial decrease in numbers of viable L monocytogenes enumerated at day 1 and showed a greater reduction in numbers throughout storage at both 4 and 10°C compared to the other treatments. For each treatment stored at 10°C, the population increased,

TABLE 1. Least squares mean differences (log CFU/pkg) between initial inoculum and growth of L monocytogenes as recovered from postpasteurized beef roasts stored at 4°C.

Storage days	TRT I	TRT 2	TRT 34	TRT 4
	Log CFU/pkg			
- <b>1</b>	2.87 <sup>t</sup>	2.82°	2.96 <sup>t</sup>	4.52*
8 .	2.31'	2.78 <sup>r</sup>	2.74'	3.95
14	2.20'	2.73*	3.20 <sup>h</sup>	3.05¢
28	0.51'	0.78 <sup>r</sup>	1.564	2.084
56	0.44'	-0.06*	-0.24#	1.07

- SEM = 0.168.
- TRT 1 (91°C, 3 min) Initial inoculum = 10.23 Log CFU/pkg.
- TRT 2 (91°C, 5 min) Initial inoculum = 9.58 Log CFU/pkg.
- TRT 3 (96°C, 3 min) Initial inoculum = 9.84 Log CFU/pkg.
- TRT 4 (96°C, 5 min) Initial inoculum = 10.99 Log CFU/pkg.
- Means within the same row with different superscripts are different (p < 0.05).

TABLE 2. Least squares mean differences (log CFU/pkg) between initial inoculum and growth of L. monocytogenes as recovered from postpasteurized beef roasts stored at 10°C.

Storage days	TRT 1°	TRT 2	TRT 3	TRT 4
	Log CFU/pkg			
1.	2.66 <sup>t</sup>	2.89	2.97!	4.19
<b>.</b> 4	2.07 <sup>f</sup>	2.42 <sup>f</sup>	2.431	3.11
8	0.76°	1.08 <sup>f</sup>	0.74'	1.87*
12	-0.05'	-0.46 <sup>r</sup>	0.62*	0.832

- SEM = 0.168.
- <sup>b</sup> TRT 1 (91°C, 3 min) Initial inoculum = 10.23 Log CFU/pkg.
- TRT 2 (91°C, 5 min) Initial inoculum = 9.58 Log CFU/pkg.
- TRT 3 (96°C, 3 min) Initial inoculum = 9.84 Log CFU/pkg.
- TRT 4 (96°C, 5 min) Initial inoculum = 10.99 Log CFU/pkg.
- Means within the same row with different superscripts are different (p < 0.05).

reaching within 1 log of, and in some cases outgrowing, the initial inoculum level by the end of the 12 d of storage (Table 2).

#### Uninoculated product

Mean counts of mesophilic organisms from uninoculated postpasteurized roasts, stored at 4 and 10°C, are represented in Fig. 1a-b. Differences in growth due to treatment were not significant for mesophilic organisms stored at 4°C until day 56 (Fig. 1a). Variations in growth due to treatment were not significant for mesophilic organisms in product stored at 10°C, with the exception of one replicate at day 8 (Fig. 1b).

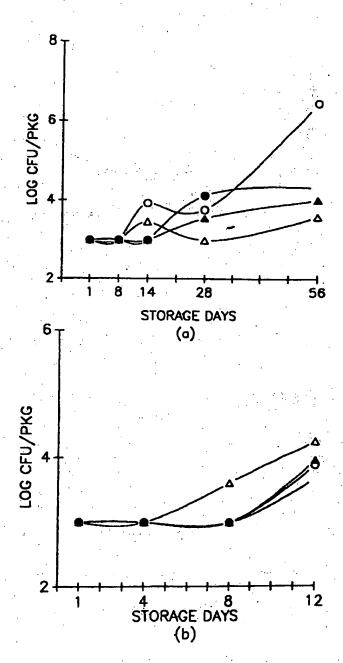


Figure 1. Growth curves for mean total counts of mesophilic organisms recovered from vacuum-packaged beef roasts postpasteurized at 91°C for 3 min (O-O TRT 1); 91°C for 5 min ( $\Phi$ - $\Phi$  TRT 2); 96°C for 3 min ( $\Delta$ - $\Delta$  TRT 4), and stored at 4°C for up to 56 d (a) and 10°C for up to 12 d (b). SEM = 0.589.

Growth trends for psychrotrophic organisms (Fig. 2a-b) were similar to the mesophiles. A longer lag phase can be seen for the product stored at 4°C (Fig. 2a). No growth was detected for psychrotrophic organisms in treatment 4 stored at 4°C (Fig. 2a). The minimum detection level was 10° for both mesophilic and psychrotrophic organisms.

Roasts were evaluated for purge on a percentage basis by the difference in weight before postpasteurization and at the time of sampling after postpasteurization. Mean averages for percent purge for roasts stored at 4 and 10°C are shown in

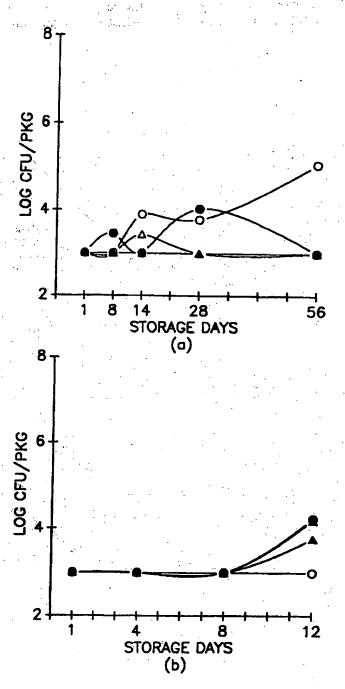


Figure 2. Growth curves for mean total counts of psychrotrophic organisms recovered from vacuum-packaged beef roasts postpasteurized at 91°C for 3 min (O-O TRT 1); 91°C for 5 min ( $\Phi$ -TRT 2); 96°C for 3 min ( $\Phi$ - $\Delta$ TRT 3); and 96°C for 5 min ( $\Phi$ - $\Delta$ TRT 4), and stored at 4°C for up to 56 d (a) and 10°C for up to 12 d (b). SEM = 0.473.

Fig. 3a-b. Treatment 1 was different (p < 0.05) from all other treatments in moisture loss at 4°C by 56 d of storage (Fig. 3a). Fig. 3b shows an overall increase in moisture loss with all treatments for product stored at 10°C as compared to products stored at 4°C. Roasts postpasteurized with shorter dwell times (TRT 1 and 3) showed an increase in percent purge over 12 d of storage at 10°C (Fig. 3b). Treatments with a 3-min dwell time (TRT 1 and 3) were different (p < 0.05) from treatments (TRT 2 and 4) with a 5-min dwell time at d 1, 8, and 12 at 10°C.

Mean values for temperatures recorded at and 3 mm below the product surface are illustrated in Fig. 4a-b. As was

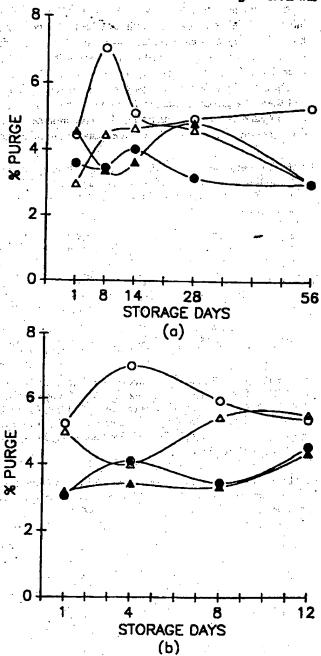


Figure 3. The average percent purge from vacuum-packaged beef roasts postpasteurized at 91°C for 3 min (O-O TRT 1); 91°C for 5 min ( $\Phi$ - TRT 2): 96°C for 3 min ( $\Delta$ - $\Delta$  TRT 3); and 96°C for 5 min ( $\Delta$ - $\Delta$  TRT 4), and stored at 4°C for up to 56 d (a) and 10°C for up to 12 d (b).

expected, postpasteurization treatments with 5-min dwell times (TRT 2 and 4) showed a higher final temperature at both the surface and 3 mm below the product surface. The greatest increase in temperature for all treatments at both surface and 3 mm below, occurred within the first minute. After this time temperatures leveled off remaining constant for all treatments.

#### **DISCUSSION**

The survival of L. monocytogenes was not unexpected with an inoculum level of 10° microorganisms per package.

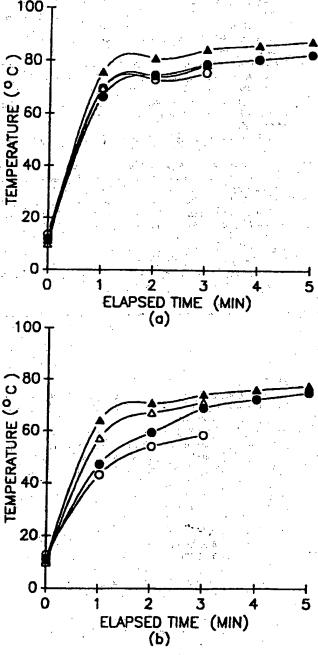


Figure 4. Time and temperature curves for mean values of temperatures taken at the product surface (a) and 3 mm below the product surface (b) every minute during postpasteurization of beef roasts at 91°C for 3 min (O-O TRT 1); 91°C for 5 min (O-TRT 2); 96°C for 3 min ( $\Delta$ - $\Delta$  TRT 3); and 96°C for 5 min ( $\Delta$ - $\Delta$  TRT 4). Note time zero is the temperature of the roasts before heat treatment.

This inoculum level was used due to the procedure used for recovery of the rganism (minimum detection level 10° CFU per pkg) and the unknown specific lethality of the chosen postpasteurization times and temperatures.

A large initial population of L. monocytogenes of the size used would not normally be expected on a product of this type. This may account in part, but not solely, for the apparent heat resistance of the organism. Boyle et al. (3) found that when high levels (>105 CFU/g) of L. monocytogenes were present in ground beef, the organism survived cooking (up to 70°C internal temperature) and subsequently multiplied when the product was stored under refrigeration (4°C). Linton et al. (12,13) suggested that exposing L. monocytogenes cells to sublethal temperatures for short periods of time significantly increases the organism's thermal resistance. An obvious difference was noted in the growth rate of L monocytogenes in samples stored at 10°C (Table 2). The organisms grew faster (p < 0.05) at this storage temperature reaching total counts in 12 d that took up to 8 weeks to attain with storage temperatures of 4°C. It is possible that the higher abuse temperature (10°C) provided an environment more conducive to repair of sublethally injured cells. This agrees with Petran and Zottola (16) who reported a shorter generation time for L. monocytogenes grown at 10°C than at 4 or 7°C. Gill and Reichel (9) found that L monocytogenes in vacuum-packaged meats grew better at 10°C than at lower temperatures.

Differences were also observed in the rate of growth of mesophilic and psychrotrophic organisms. Treatments with higher temperatures and longer dwell times (TRT 2, 3, and 4) were different (p < 0.05) from TRT 1 during 8 weeks of storage (4°C) for both types of organisms (Fig. 1a and 2a). All postpasteurization treatments, with the exception of TRT 1, day 56, appeared to keep the numbers of both mesophilic and psychrotrophic organisms low (<10' CFU per pkg), possibly allowing for increased growth of L. monocytogenes. However, the total counts for mesophilic and psychrotrophic organisms agree with Bently (2), who found a significant decrease in total counts of aerobic, anaerobic, and lactobacilli organisms in pasteurized (205°F for 3, 5, or 10 min) versus unpasteurized beef roasts. Total numbers of aerobic organisms for beef postpasteurized at 205°F (96°C) for 5 min were below 10<sup>3</sup> after 8 weeks of storage. This factor has been noted as a problem for the new generation of extended shelf-life refrigerated foods. Corlett (5) cautions that the utilization of new process methods to extend product shelf life may prevent "normal" warning of food safety hazards by destruction of spoilage flora. This stresses the importance of finding the most appropriate times and temperatures to be used to insure product safety using postpasteurization.

One of the major advantages of cook-in products has been increased product yield. The results of this study showed a decreased loss of moisture with higher dwell times and higher temperatures which remained fairly constant throughout extended storage at both 4 and 10°C. This factor is important for processors, who do not want to decrease product yield by additional use of the postpasteurization process.

The heat-resistance data obtained from this study of L. monocytogenes indicate that specific guidelines need to be set for the postpasteurization process. This is to insure the

destruction of potentially pathogenic, thermally resistant organisms that may survive the refrigerated storage necessary in extended shelf-life products, such as cook-in-strip. Further studies using a variety f products to more accurately set applicable time and temperatures for the use of postpasteurization in industry are appropriate. Results of this study found that for a product such as half eye of round roasts, a postpasteurization temperature f 96°C for a dwell time of 5 min was most effective, providing for a greater decrease in total numbers of L. monocytogenes when compared with the initial inoculum and results from the other treatments.

#### REFERENCES

- American Meat Institute, 1988. Interim guideline: microbial control during production of ready-to-eat meats. Controlling the incidence of Listeria monocytogenes. American Meat Institute, Washington, DC.
- Bently, D. S. 1988. Shelf life of whole muscle roast beef. Unpublished report. W. R. Grace & Co., Cryovac Div., Duncan, SC.
- Boyle, D. L., J. N. Sofos, and G. R. Schmidt. 1990. Thermal destruction of *Listeria monocytogenes* in a meat slurry and in ground beef. J. Food Sci. 55(2):327-329.
- Cooksey, D. K. 1992. Effects of post-pasteurization and refrigerated storage on the quality of precooked beef. M.S. thesis. University of Illinois, Urbana Champaign, IL.
- Corlett, D. A. 1989. Refrigerated foods and use of hazard analysis and critical control point principles. Food Technol. 43(2):91-94.
- DeMasi, T. W., and K. R. Deily. 1990. Cooked meats packaging technology. pp. 117-121. In Proc. Reciprocal Meat Conference, vol. 43. National Livestock and Meat Board, Chicago.
- Food Safety and Inspection Service. 1989. Revised policy for controlling Listeria monocytogenes. Fed. Reg. 54(98):22345-22346.
- Fraser, J. A., and W. H. Sperber. 1988. Rapid detection of *Listeria* spp. in food and environmental samples by esculin hydrolysis. J. Food Prot. 51:762-765.

- Gill, C. O., and M. P. Reichel. 1989. Growth of cold-tolerant pathogens Yersinia enserocolitica, Aeromonas hydrophila and Listeria monocytogenes on high-pH beef packaged under vacuum of carbon dioxide. Pood Microbiol. 6:223-230.
- Johnson, J. L., M. P. Doyle, and R. G. Cassens. 1990. Listeria monocytogenes and other Listeria spp. in mest and mest products: A review. J. Food Prot. 53:81-91.
- Lee, W. H., and McClain, D. 1989. Laboratory communication No. 57 (revised May 24, 1989). USDA, FSIS Microbiology Division, Bethesda, MD.
- Linton, R. H., M. D. Pierson, and J. R. Bishop. 1990. Increase in resistance of *Listeria manocytogenes* Scott A by sublethal heat shock. J. Food Prot. 53:924-927.
- Linton, R. H., M. D. Pierson, J. R. Bishop, and C. R. Hackney. 1992.
   The effect of sublethal heat shock and growth atmosphere on the heat resistance of Listeria monocytogenes Scott A. J. Food Prot. 55:84-87.
- Lowry, P. D., and I. Tiong. 1988. The incidence of Listeria monocytogenes in meat and meat products factors affecting distribution. pp. 528-530. In Proc. 34th Int. Congress Meat Sci. Technol., Brisbane, Australia.
- McClain, D., and W. H. Lee. 1988. Development of USDA-FSIS method for the isolation of *Listeria monocytogenes* from raw ment and poultry. J. Assoc. Off. Anal. Chem. 71:660-664.
- Petran, R. L., and E. A. Zottola. 1989. A study of factors affecting growth and recovery of *Listeria monocytogenes* Scott A. J. Food Sci. 54:458-460.
- SAS. 1985. SAS user's guide. Statistical Analysis System Institute. Inc., Cary, NC.
- Skovgaard, N., and C. Morgen. 1988. Detection of Listeria spp. in facces from animals, in feeds, and in raw foods of animal origin. Int. J. Food Microbiol. 5:229-242.
- Terlizzi, F. M., R. R. Perdue, and L. L. Young. 1984. Processing and distributing cooked meats in flexible films. Food Technol. 3:67-71.
- Toledo, R. T. 1991. Fundamentals of food process engineering, 2nd ed. Van Nostrand Reinhold, New York.
- Wehr, H. M. 1987. Listeria monocytogenes—a current dilemma. J. Assoc. Off. Anal. Chem. 70:769-772.
- Weis, J., and H. P. R. Seeliger. 1975. Incidence of Listeria monocytogenes in nature. Appl. Microbiol. 30:29-32.

#### M ore and Madden, cont. from p. 654

Maintenance of a high standard of hygiene and temperature control during packaging and distribution of the product should ensure that it presents no risk of listeriosis to the consumer.

#### ACKNOWLEDGMENT

This work was supported by a grant from the Department of Education for Northern Ireland and by Gracey Foods Ltd., Northern Ireland.

#### REFERENCES

- Board, R. G. 1977. The Microbiology of eggs. pp. 49-64. In W. J. Stadelman and O. J. Cotterill (ed.) Egg science and technology. AVI Publishing Co., Westport, CT.
- Buchanan, R. L., H. G. Stahl, and D. L. Archer. 1987. Improved plating media for the simplified quantitative detection of *Listeria* monocytogenes in foods. Food Microbiol. 4:269-275.
- Cox, L. J., A. Siebenga, C. Pedrazinni, and J. Moreton. 1991. Enhanced haemolysis agar (EHA) - an improved selective and differential medium for isolation of *Listeria monocytogenes*. Food Microbiol. 8:37-49.
- Curtis, G. D. W., R. G. Mitchell, A. F. King, and E. J. Griffin. 1989.
   A selective differential medium for the isolation of *Listeria monocytogenes*. Lett. Appl. Microbiol. 8:95-98.
- 5. Henry, B. S. 1933. Dissociation of the genus Brucella. J. Infect. Dis.

52:374-402.

- Fleming, D. W., S. L. Cochi, K. L. MacDonald et al. 1985. Pasteurized milk as a vehicle of infection in an outbreak of listeriosis. N. Engl. J. Med. 312:404-407.
- Foegeding, P. M., and S. B. Leasor. 1990. Heat resistance and growth of *Listeria monocytogenes* in liquid whole egg. J. Food Prot. 53:9-14.
- Foegeding, P. M., and N. W. Stanley. 1990. Listeria monocytogenes F5069 thermal death times in liquid whole egg. J. Food Prot. 53:6-8.
- James, S. L., S. M. Fannin, B. A. Agee et al. 1985 Listeriosis outbreak associated with Mexican-style cheese. Morbid. Mortal. Weekly Rep. 34:357-359.
- Leasor, S. B., and P. M. Foegeding. 1989. Listeria species in commercially broken raw liquid whole egg. J. Food Prot. 52:777-780.
- Lee, W. H., and D. McClain. 1986. Improved Listeria monocytogenes selective agar. Appl. Environ. Microbiol. 52:1215-1217.
- Lovett, J., D. W. Francis, and J. M. Hunt. 1987. Listeria monocytogenes in raw milk: detection, incidence and pathogenicity. J. Food Prot. 50:188-192.
- McClain, D., and W. H. Lee. 1988. Development of USDA-FSIS method for isolation of *Listeria monocytogenes* from raw meat and poultry. J. Assoc. Off. Anal. Chem. 71:660-664.
- Schlech, W. F., P. M. Lavigne, R. L. Bortolussi, A. C. Allen, E. V. Haldane, A. J. Wort, A. W. Hightower, S. E. Johnson, S. H. King, E. S. Nicholls, and C. V. Broome. 1983. Epidemic listeriosis evidence for transmission by food. N. Engl. J. Med. 308:203-206.
- Weis, J., and H. P. R. Seeliger. 1975. Incidence of Listeria monocytogenes in nature. Appl. Microbiol. 30:29-32.

## Proceedings of the

# FOOD PRESERVATION 2000 CONFERENCE

19-21 October 1993
Natick, Massachusetts USA

Workshop Proceedings prepared by: SCIENCE AND TECHNOLOGY CORPORATION 101 Research Drive, Hampton, Virginia 23666-1340 757/865-7604

#### FOOD PRESERVATION BY HURDLE-TECHNOLOGY

L. Leistner, H. Hechelmann Federal Centre for Meat Research D-95326 Kulmbach, Germany

#### ABSTRACT

The microbial stability and safety of most foods is based on a combination of several factors (hurdles). From an understanding of the hurdle-effect, the hurdle-technology has been derived which allows improvements of the safety as well as the quality of foods by an intelligent combination of hurdles. Total quality of a food is achieved by keeping the safety and quality hurdles in the optimal range. More than 40 potential hurdles suitable for food preservation have hitherto been identified. A multi-target disturbance of the homeostasis of microorganisms could be accomplished by hurdletechnology, resulting in a gentle but most effective preservation of foods. The efficiency of hurdletechnology for food preservation was demonstrated in a study (supported by the Medical Corps of the German Army) on meat products with fresh-product-characteristics which nevertheless are storable without refrigeration. In co-operation with 24 German meat processors in total 75 meat products were selected which fulfil these requirements. It was revealed that these tasty and stable products represent eight categories, based on different principles of hurdle-technology. These categories include quick fermented sausages, mini-salami, F-SSP, aw-SSP, repasteurized aw-SSP, pH-SSP, Combi-SSP, and autoclaved flat pouches. Since these meats should be suitable for army provisions produced by different enterprises, the manufacturing processes must be standardised and reproducible. Therefore, a linkage between hurdle-technology and the HACCP-concept was introduced. In the manufacturing plants processing the meats recommended, no microbiological tests have to be carried out, however, other process parameters have to be controlled strictly, and these are: time, temperature, pH, and aw. These measurements should be done on-line, or at least at-line. A new instrument became available which allows reliable aw determinations of meat products within 10 to 20 minutes. In conclusion, hurdle-technology is a fast moving and most promising field, since it provides stable and tasty foods well accepted by the consumer.

#### 1. INTRODUCTION

The hurdle-technology has been introduced and further developed by our laboratory (Leistner, 1978; 1985; 1987, 1992, 1993; 1994), and proved very useful in the optimization of traditional foods as well as in the design of novel food products.

#### 1.1 GENERAL ASPECTS OF HURDLE-TECHNOLOGY

The stability an safety of most foods is based on a combination of several factors (e.g., temperature, pH, a<sub>W</sub>, Eh, competitive flora, preservatives), also called barriers or hurdles. This has been illustrated by the so-called hurdle-effect (Leistner, 1978; 1992). According to this concept the microorganisms present ("on the start") in a food should not be able to overcome ("overjump") the

hurdles present, otherwise the food will spoil or even cause food poisoning. For each stable and safe food a certain set of hurdles is inherent, which differ in quality and intensity depending on the product, however, they should keep the "normal" population of microorganisms in the food under control. If there are only few microorganisms present at the start, then a few or low hurdles are sufficient for the stability of the product. The aseptic packaging of perishable foods is based on this principle. However, if due to bad hygienic conditions too many undesirable organisms are initially present, then even the usual hurdles inherent in a product cannot prevent spoilage or food poisoning. Furthermore, in a food superior in nutrients and vitamins, which could foster the growth of microorganisms ("trampoline effect"), the hurdles must be enhanced, otherwise they will be overcome. On the other hand, sublethally damaged microorganisms in foods are already inhibited by fewer or lower hurdles. If, for instance, bacterial spores in a food are sublethally injured by heat, then the vegetative cells derived from such spores lack vitality and thus are easily inhibited by hurdles. In some foods, such as fermented sausages, raw hams, and probably also in ripened cheeses, the microbial stability is achieved during processing by a sequence of hurdles, which are important in different stages of the ripening process and lead to a stable final product.

An important phenomenon, which deserves attention in food preservation is the homeostasis of microorganisms (Gould, 1988). In foods preserved by hurdle-technology the possibility that different hurdles in a food might not just have an additive effect on the stability, but could act synergistically is of particular interest (Leistner, 1978). This could be true, if the hurdles in a food hit different targets (e.g., cell membrane, DNA, enzyme systems, pH, a<sub>W</sub>, Eh) within the microbial cell, and thus disturb the homeostasis of the microorganisms present in several respects. Under practical terms this could mean, it is e.g. more effective to use several and different preservative factors in small amounts in a food, than just one strong hurdle (Leistner, 1994). The multi-target preservation of foods could become a promising research field, since it would accomplish a gentle but most effective preservation of foods.

The hurdle-effect is of fundamental importance for the preservation of foods, since the hurdles in a stable product control microbial spoilage and food poisoning as well as the desirable fermentation processes (Leistner et al., 1981). Furthermore, these authors acknowledged that the hurdle concept illustrates only the well-known fact that complex interactions of aw, pH, temperature, etc. are significant in the microbial stability of foods. From the hurdle-effect the hurdle-technology (also called combined processes, combined methods, combination preservation, combination techniques, barrier technology) has been derived, since an intelligent combination of hurdles secures the microbial stability as well as the sensory, nutritive, toxicological and economic properties of a food.

The most important hurdles commonly used in food preservation, either applied as process or additive hurdles, are high temperature (F value), low temperature (t value), water activity (a<sub>w</sub>), acidity (pH), redox potential (Eh), preservatives (e.g., nitrite, organic acids), and competitive microorganisms (e.g., lactic acid bacteria). However, in addition more than 40 hurdles of potential use for foods of animal or plant origin, which improve the stability and/or quality of these products, have hitherto been identified. These include oxygen tension (low or high), modified atmosphere (carbon dioxide, nitrogen, oxygen) pressure (high or low), radiation (UV, microwaves, irradiation), other physical processes (ohmic heating, pulsed electric fields, pulsed light processing, ultrasonication), new packaging (selective permeable films, advanced edible coatings, "smart" materials), preservatives (e.g., trisodium phosphate, ethanol, free fatty acids, Maillard reacti n products, spice extracts, lysozymes, nisin, other bacteriocines), and the food microstructure

(emulsions, solid-state-fermentation). The list of possible hurdles for the preservation of foods is by no means closed, however, not all of these hurdles will be commonly applied, and certainly not all of them for the same food product.

If a food is not comminuted, but consists of large pieces of plant or animal tissue, a protection against microbial deterioration might be achieved by a surface layer on the food, which contains and maintains inhibitory substances (hurdles). An example is Pastirma, a raw beef product traditional in Moslem countries, for which an edible surface coating (containing garlic, other spices, and a binder) is used, which inhibits mold growth on the surface and inactivates salmonellae inside of the food (Leistner, 1987). In model foods Torres (1987) studied the surface microbial stability by using coatings which maintain preservatives and the desired low pH, and he demonstrated that a low pH in the surface layer greatly improved the effectiveness of sorbic acid in the coating. Guilbert (1988) used superficial edible layers for easily perishable tropical fruits, and achieved a preservation without affecting the integrity of the food pieces.

Moreover, the so-called osmotic dehydration, a dewatering and impregnation process which consists of soaking foods (fruits, vegetables, meat, cheese, fish) in highly concentrated solutions of sucrose, sodium chloride or other humectants, could generally be employed for solute transfer from a solution into the product (Lerici et al., 1988). By this process not only water activity lowering agents could be inserted into integer foods, but also preservatives and nutrients as well as substances which control the pH, texture and flavor, and thus build into the product hurdles which improve the stability as well as the quality of the food (Raoult-Wack et al., 1992). Also this application of hurdle-technology could find many applications.

Stanley (1991) indicated that the hurdle-technology approach seems to be applicable to a wider concept of food preservation, than just microbial stabilty, and he suggested that e.g. the oxidation of plant and animal membrane lipids is influenced by a number of positive and negative extrinsic and intrinsic factors. Undoubtedly, hurdle-technology is not only applicable to the safety, but also to quality aspects of foods. Some hurdles (e.g., Maillard reaction products) influence the safety as well as the quality of foods (Stecchini et al., 1991), and this applies to several other hurdles. The possible quality hurdles in foods might influence the sensory, nutritive, technological, and economic properties of a product, and the hurdles present might be negative as well as positive for securing the desired total quality of a food. Moreover, the same hurdle could have a positive or a negative effect on food quality, depending on its intensity. For instance, too quick and too low chilling will be detrimental to fruit quality, whereas moderate chilling is beneficial. An other example is the pH of fermented sausages, which should be low enough to inhibit pathogens, but not so low as to impair taste. In order to secure the total quality of a food, the safety and quality hurdles should be kept in the optimal range (Leistner, 1994).

### 1.2 APPLICATION OF HURDLE-TECHNOLOGY

Foods based on hurdle-technology are common in industrialized as well as in developing countries. For a long time hurdle-technology was applied empirical without knowing the governing principles. For instance, the traditional Italian mortadella, an emulsion type sausage storable without refrigeration, harbors due t a mild heat process (78°C core temperature) still bacterial spores. However, bacilli and clostridia are inhibited in genuine mortadella by a decreased a<sub>W</sub> (below 0.95), and this adjustment (by salt, milk powder, and drying) was done for a long time without knowledge of the reason (Leistner et al., 1981). Other examples of empiric applied hurdle-technology revealed

an extensive study done in Latin America on traditional foods of the region storable without refrigeration. In the course of this study (CYTED-D PROGRAMA) in total 266 food items, representing fruits, vegetables as well as foods derived from milk, fish, cereals and meat, were identified which are stable and safe without refrigeration. The majority of these items were intermediate moisture foods, however, many were based on empirical applied hurdle-technology, since their aw was in some instances as high as 0.97 (Aguilera et al., 1990).

Often the stability and safety of intermediate moisture foods (IMF), which have an  $a_W$  in the range of 0.90 to 0.60, is also based on hurdle-technology (Leistner and Rödel, 1976). If the  $a_W$  of IMF is quite low, then the addition of too high amounts of humectants (such as salt or sugar) is required, and this could be undesirable from the sensory and nutritional point of view. Therefore, efforts are made to improve the quality of such foods by decreasing the sugar and salt addition, as well as by increasing the moisture content and  $a_W$ , however, without sacrificing their microbial stability and safety if stored without refrigeration. This is achieved by an intelligent application of hurdles. A case in point is a novel dried meat product of China based on hurdle-technology, because the traditional product (Rou Gan) had an  $a_W$  below 0.70, whereas the new product (Shafu), with much superior sensory properties, has an  $a_W$  of about 0.79 (Wang and Leistner, 1993). In addition, it could be mentioned that pet foods used for cats and dogs had before application of hurdle-technology an  $a_W$  of about 0.85 and thus contained excessive amounts of propylene glycol, but they are now stable and safe unrefrigerated with an  $a_W$  as high as 0.94, which improves the nutritional, sensory and economic properties of these novel pet products.

Traditional and novel high moisture foods (HMF), with an aw above 0.90, which are storable without refrigeration, are on the increase too. Before they were produced empirical, but now often by an intelligent application of hurdle-technology. This is true e.g. for raw, fermented sausages (salami), where by a sequence of hurdles the food poisoning and spoilage organisms are inhibited, and the desired competitive flora (lactic acid bacteria) is selected. Important hurdles in the early stage of the ripening process of salami are nitrite and salt, which inhibit many of the bacteria in the batter, others multiply and cause the oxygen tension and the redox potential of the product to decrease, and this in turn enhances the Eh hurdle, which inhibits aerobic organisms and favors the selection of lactic acid bacteria, which then flourish, cause acidification of the product and thus an increase of the pH hurdle. In long-ripened salami the nitrite is depleted and the lactics decrease, while the Eh and pH increase somewhat. Therefore, only the aw hurdle is strengthened with time, and it is mainly responsible for the stability of long-ripened raw sausage (Leistner, 1987). Since this sequence of hurdles has been revealed, the production of fermented sausages became less empiric and more advanced.

Heated high moisture foods based on hurdle technology, and thus storable without refrigeration, are shelf-stable products (SSP), which offer the following advantages: the mild heat treatment (70 to 110°C) improves the sensory and nutritional properties of the food, and the lack of refrigeration simplifies distribution and saves energy during storage. SSP are heated in sealed containers (casings, pouches, or cans) which avoid recontamination, but they still contain viable spores of bacilli and clostridia, which are inhibited by the adjustment of a<sub>w</sub>, pH, and Eh as well as in the case of autoclaved sausages by a sublethal injury of these spores. Different types of SSP meats are distinguishable, depending on the primary hurdles, even additional hurdles foster their safety and stability. In one type, the F-SSP, the sublethal damage of spores is the primary hurdle, and an example are autoclaved sausages which in a considerable variety are prevalent since about ten years in German supermarkets. They are stored unrefrigerated for several weeks, and have caused no problems with regard to food poisoning or spoilage, because guidelines for their processing have

been suggested (Hechelmann and Leistner, 1984). The stability of another type, the aw-SSP, is primarely caused by the reduction of the water activity below 0.95, and examples are the Italian mortadella and the German brühdauerwurst, and guidelines for their processing have been suggested (Leistner, 1987). In the third type, the pH-SSP, an increased acidity is the primary hurdle, and this principle is e.g. applied in novel gelderse rookworst, as mentioned by Leistner (1987), which is storable without refrigeration and is exported by the Netherlands in large quantities to Britain. Finally in the fourth type, the Combi-SSP, a combination of equal hurdles is applied, each of those adds a little weight on an imaginary balance, which should swing from the unstable to a stable state of the product (Leistner, 1992). A variety of brühwurst products is now stabilized as Combi-SSP.

Not only meat products but dairy products too could be produced as Combi-SSP. A case in point is paneer, a cottage cheese type product with tomato sauce, onions and spices, frequently consumed and much liked in India, because of its nutritive value and characteristic taste. However, consumed and much liked in India, because of its nutritive value and characteristic taste. However, paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer spoils at room temperature (in India often at 35°C) within two days. Together with a visiting paneer in cans, the spoils at 15°C at 15°C at

### 2. HURDLE-TECHNOLOGY APPLIED TO ARMY PROVIONS

The Federal Centre for Meat Research at Kulmbach, Germany, has received a research grant from the Medical Corps of the German Army, which had the objective to explore the potentials for using meat products stabilized by hurdle-technology as army provisions. Such products would be attractive if they taste like fresh and need no refrigeration.

### 2.1 EXECUTION OF THE ARMY PROJECT

Meat products should be recommended which have fresh-product-characteristics, and should be safe, stable and tasty for at least six days at 30°C. Refrigeration must not be required, because these rations have to be used during military exercises. The meats selected should be real products, already on the German market, however, if necessary their stability should be improved by a modification of the product. We asked German meat processors to name us meat products which taste

### TABLE 1. CATEGORIES OF THE RECOMMENDED MEATS

- 1. Quick-ripened fermented sausage.
- 2. Mini-salami (two different types).
- 3. Brühwurst and liver sausage as F-SSP.
- 4. Dried brühwurst as aw-SSP.
- 5. Repasteurized brühwurst as aw-SSP.
- 6. Brawns and brühwurst as pH-SSP.
- 7. Items of brühwurst as Combi-SSP.
- 8. Brühwurst in autoclaved flat pouches.

like bought in delicatessen shops, but need no refrigeration. This invitation followed 24 manufacturers and they suggested 100 of their products, of which 75 proved safe and stable after incubation. We bought from each of these stable items ten samples and scrutinized them for their physical, chemical, microbiological and technological characteristics. The results obtained have revealed that these tasty and stable 75 items represented eight categories, with the safety and stability based on different principles of hurdle-technology (Hechelmann et al., 1991). These eight categories are listed in Table 1.

### 2.2 DESCRIPTION OF THE SELECTED MEATS and the latest the second of the s

A detailed description of the composition and processing of the selected meat product has been given in our Final Report (Hechelmann et al., 1991), which was published by the Medical Corps of the German Army. An English translation of these results is in preparation. The details are voluminous and thus cannot be repeated here. However, the most important critical control points (CCP's) for each of the eight categories of meat products are listed in Table 2.

TABLE 2. PROMINENT CCP's FOR THE SELECTED MEATS TO THE SELECTED MEATS TO THE SELECTED MEATS TO THE SELECTED MEATS.

Category	Most important critical control points
1. Quick fermented sausage	pH below 5.4; aw below 0.95; starter cultures; smoke; (modified atmosphere).
2. Mini-salami	As fermented sausage: a <sub>w</sub> below 0.82. As dried brühwurst: a <sub>w</sub> below 0.85.
	Aluminium-packed in order to exclude light as well as oxygen.
3. F-SSP	F above 0.4; a below 0.97 or 0.96; pH below 6.2; PVDC casings.
4. a <sub>W</sub> -SSP	Product core temperature above 75°C; a <sub>w</sub> below 0.95; uncut surface; smoke.
5. Repasteurized aw SSP	Temperature above 75°C; a <sub>W</sub> below 0.95; pH below 6.2; after packaging heated for 45 min at 82 - 85°C.
6. pH-SSP	pH below 5.2; hot filled and heated to a core temperature above 72°C.
7. Combi-SSP	Low initial spore count; nitrite at least 100 ppm; core temperature above 72°C; aw below 0.965; pH below 5.8; after packaging 45 - 60 min at 82 - 85°C.
8. Flat pouches	Aluminium foil with vacuum; diameter less than 3 cm; F value more than 2.5 ("botulinum cook").

ang an<mark>aka di 16</mark> Mga mga da dagar

### 2.3 LINKAGE OF HURDLE-TECHNOLOGY WITH HACCP

Since large and small enterprises must be able to manufacture meat products suitable for army provisions, in case they obtain a contract, the processes have to be spelled out in detail, in order to become standardized and reproducible. This detailed description we have done on the basis of the HACCP concept, and for products of each of the eight categories of the selected meats for the process control 15 - 20 critical control points (CCP's) have been defined; the most important CCP's are listed in Tab. 2. Herewith for the first time a linkage between hurdle-technology and the HACCP concept was introduced (Hechelmann et al., 1991; Leistner, 1993).

In the processing of the meats recommended, no microbiological tests are necessary in the manufacturing plants, however, other parameters have to be controlled strictly, and these are: time, temperature, pH, and a<sub>W</sub>. These measurements should be done on-line or at least at-line. To measure quickly time, temperature and pH poses no problems, however, the measurement of the water activity with conventional instruments takes about 3 - 4 hours. Fortunately, now a new instrument (aw-Kryometer) is available, which allows very reliable aw determinations of meat products within 10 - 20 minutes (Rödel et al., 1989).

The army project also raised the question, how food design should be done in general, by applying hurdle-technology combined with HACCP, and possibly with predictive microbiology too. The predictive microbiology (Gould, 1989; McClure et al., 1993; McMeeking et al., 1993) is a promising concept which allows computer-based predictions of microbial growth, survival and death in foods. However, the models feasible for predictive microbiology can hitherto manage only relatively few parameters (hurdles), i.e. temperature, pH, aw, aerobic or anaerobic conditions, and few preservatives (e.g., nitrite or lactic acid or carbon dioxide). As mentioned above, there are numerous other potential hurdles, which are important for the stability and safety of foods. Thus, predictive microbiology cannot be considered to be a quantitative approach to hurdle-technology, and it cannot replace challenge-tests of foods with relevant microorganisms. However, predictive microbiology can narrow down considerably the range in which challenge-testing must be done, and this certainly saves time and costs in product development.

In Table 3 for the design of foods 10 steps are suggested (Leistner, 1993; unpublished data), which have proved approriate in the development of modified or novel food products.

### 3. CONCLUSIONS

Hurdle-technology allows a gentle but efficient preservation of safe, stable, nutritious, and tasty foods storable without refrigeration. This has been demonstrated by the selection and improvement of meat produts with fresh-product-characteristics, storable without refrigeration, and suitable for army provisions during military exercises.

The application of hurdle-technology is approriate for chilled foods too, because even in case of temperature abuse the safety and stabilty of these products will be maintained.

For the optimization of traditi nal as well as for the development of novel foods a ten step procedure is suggested which could prove useful in food design, since it combines hurdle-technology, predictive microbiology and HACCP.

### TABLE 3. RECOMMENDED STEPS FOR FOOD DESIGN

- 1. First, for the modified or novel food product the desired sensory properties and the desired shelf-life must be defined.
- 2. Secondly, a tentative technology for the production of the food should be layed down.
- 3. The food is now manufactured according to this technology, and the resulting product is analyzed for pH, aw, preservatives or other inhibitory factors, and the temperatures for heating (if intended) and storage are defined.
- 4. For preliminary stability testing of the suggested food product, predictive microbiology should be employed.
- 5. The product is now challenged with food-poisoning and spoilage microorganisms, using somewhat higher inocula and storage temperatures than "normal".
- 6. If necessary the hurdles in the product are modified, taking the homeostasis of the microorganisms and the sensory quality of the food (i.e., "total quality") into consideration.
  - 7. The modified product is again challenged with relevant microorganisms, and if necessary the hurdles are modified once more. Predictive microbiology for assessing the safety of the food might be helpful at this stage too.
- 8. Now the established hurdles of the modified or novel food are exactly defined, including tolerances. Then the methods for monitoring the process are defined (preferably physical methods should be used).
- 9. Thereafter, the designed food should be produced under industrial conditions, because the possibilities for a scale-up of the proposed process must be validated.
- 10. Finally, for the industrial process the critical control points (CCP's) and their monitoring has to be established, and thus the manufacturing process should be controlled by HACCP.

### ACKNOWLEDGMENT

For their motivation and diligent support during the execution of the army project, we would like to thank Ralf Kasprowiak, Stefan Reil, and Andrea Bergmann.

### **REFERENCES**

Aguilera, J.M., Chirife, J., Tapia, M.S., Welti, J., and E. Parada Arias (Eds.), 1990: Inventario de Alimentos de Humedad Intermedia Tradicionales de Iberoamérica, Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Biotecnologia, México, 557 pp.

Gould, G.W., 1988: Interference with homeostasis - food. In *Homeostatic Mechanisms in Micro-organisms*, R. Whittenbury, G.W. Gould, J.F. Banks and R.G. Board (Eds.), FEM Symposium No. 44, 220-228.

- Gould, G.W., 1989: Predictive Mathematical Modelling of Microbial Growth and Survival in Foods, Food Science & Technology Today, 3, 89-92.
- Guilbert, S., 1988: Use of superficial edible layer to protect intermediate moisture foods: application to the protection of tropical fruit dehydrated by osmosis. In *Food Preservation by Moisture Control*, C.C. Seow (Ed.), Elsevier Applied Science Publishers, London, 199-220.
- Hechelmann, H., and L. Leistner, 1984: Mikrobiologische Stabilität autoklavierter Darmware, Mitteilungsblatt der Bundesanstalt für Fleischforschung, Kulmbach, Germany, No. 84, 5894-5899.
- Hechelmann, H., Kasprowiak, R., Reil, S., Bergmann, A., and L. Leistner, 1991: Stabile Fleischerzeugnisse mit Frischprodukt-Charakter für die Truppe. BMVg FBWM 91-11, Dokumentations- und Fachinformationszentrum der Bundeswehr, Bonn, Germany, 129 pp.
- Leistner, L., and W. Rödel, 1976: The stability of intermediate moisture foods with respect to micro-organisms. In *Intermediate Moisture Foods*, R. Davies, G.G. Birch and K.J. Parker (Eds.), Applied Science Publishers, London, 120-137.
- Leistner, L., 1978: Hurdle effect and energy saving. In Food Quality and Nutrition, W.K. Downey (Ed.), Applied Science Publishers, London, 553-557.
- Leistner, L., Rödel, W., and K. Krispien, 1981: Microbiology of meat and meat products in high- and intermediate-moisture ranges. In *Water Activity: Influences on Food Quality*, L.B. Rockland and G.F. Stewart (Eds.), Academic Press, New York, 855-916.
- Leistner, L., 1985: Hurdle technology applied to meat products of the shelf stable product and intermediate moisture food types. In *Properties of Water in Foods in Relation to Quality and Stability*, D. Simatos and J.L. Multon (Eds.), Martinus Nijhoff Publishers, Dordrecht, 309-329.
- Leistner, L., 1987: Shelf-stable products and intermediate moisture foods based on meat. In Water Activity: Theory and Applications to Food, L.B. Rockland and L.R. Beuchat (Eds.), Marcel Dekker, New York, 295-327.
- Leistner, L., 1992: Food Preservation by Combined Methods, Food Research International, 25, 151-158.
- Leistner, L., 1993: Linkage of hurdle-technology with HACCP. *Proc. 45th Annual Reciprocal Meat Conference*, American Meat Science Association, National Live Stock and Meat Board, Chicago, 1-3.
- Leistner, L., 1994: Further Development in the Utilization of Hurdle-Technology for Food Preservation, J. Food Engineering, accepted.
- Lerici, C.R., Mastrocola, D., Sensidoni, A., and M. Dalla Rosa, 1988: Osmotic concentration in food processing. In *Preconcentration and Drying of Food Materials*, S. Bruin (Ed.), Elsevier Applied Science Publishers, Amsterdam, 123-134.

McClure, P.J., Baranyi, J., Boogard, E., Kelly, T.M., and T.A. Roberts, 1993: A Predictive Model for the Combined Effect of pH, Sodium Chloride and Storage Temperature on the Growth of Brochothrix thermosphacta, Internat. J. Food Microbiol., 19, 161-178.

McMeekin, T.A., Olley, J.N., Ross, T., and D.A. Ratkowsky, 1993: Predictive Microbiology: Theory and Application, Research Studies Press. Taunton, England, 340 pp.

Rödel, W., Scheuer, R., and H. Wagner, 1989: Neues Verfahren zur Bestimmung der Wasseraktivität bei Fleischerzeugnissen, Fleischwirtschaft, 69, 1396-1399.

Rao, K.J., Dresel, J., and L. Leistner, 1992: Anwendung der Hürden-Technologie in Entwicklungsländern, zum Beispiel für Paneer, Mitteilungsblatt der Bundesanstalt für Fleischforschung, Kulmbach, Germany, 31, 293-297.

Rao, K.J., 1993: Application of hurdle technology in the development of long life paneer-based convenience food. Ph.D. Thesis, National Dairy Research Institute, Karnal, India, 195 pp.

Raoult-Wack, A.L., Lenart, A., and S. Guilbert, 1992: Recent advances in dewatering through immersion in concentrated solutions. In *Drying of Solids*, A.S. Mujumdar (Ed.). International Science Publishers, New York, 21-51.

Stanley, D.W., 1991: Biological Membrane Deterioration and associated Quality Losses in Food Tissues, Critical Reviews in Food Science and Nutrition, 30, 487-553.

Stecchini, M.L., Giavedoni, P., Sarais, I., and C.R. Lerici, 1991: Effect of Maillard Reaction Products on the Growth of Selected Food-Poisoning Micro-organisms, Letters in Applied Microbiology, 13, 93-96.

Torres, J.A., 1987: Microbial stabilization of intermediate moisture food surfaces. In *Water Activity: Theory and Applications to Food*, L.B. Rockland and L.R. Beuchat (Eds.), Marcel Dekker, New York, 329-368.

Wang, W., and L. Leistner, 1993: Shafu - a Novel Dried Meat Product of China based on Hurdle-Technology, Fleischwirtschaft, 73, 854-856.

erstood ط. This is preonse to s reguogether ∕e been : needs f scienr in an aly and dia are rn, but accuas has **ISL** d risks ' panel :tically ambers. nanges ing to ne had

iss of ity of attend act of 1 Joss rovid-

ie per-

voiced

UK Bioand forable Joss tel.

UK ance um,  The Lay Panel Preliminary Report: UK National Consensus Conference on Plant Bintechnology 2-4 November 1994 (1994), p. 3, Science Museum, London, UK

8 The Lay Panel Preliminary Report: UK National Consensus Conference on Plant Biotechnology 2–4 November 1994 (1994), p. 8, Science Museum, London, UK

 The Lay Panel Preliminary Report: UK National Consensus Conference on Plant Biotechnology 2-4 November 1994 (1994), p. 10, Science Museum, London, UK

- 10 Mestel, R. (1994) New Sci. 144, 4
- 11: The Lay Panel-Preliminary Report: UK National Consensus Confesence on Plant Biotechnology 2–4 November 1994 (1994), p. 12, Science: Museum, London, UK
- 12 House of Lords Select Committee Report on the Regulation of the UK Biotechnology Industry and Global Competitiveness 13 July 1993 (1993), HMSO, London, UK

NOTICE: This material may be protected by copyright law (Title 17 U.S. Code)

### Review

Hurdle technology was developed several years ago as a new concept for the production of safe, stable, nutritious, tasty and economical foods. It advocates the intelligent use of combinations of different preservation factors or techniques ('hurdles') in order to achieve multi-target, mild but reliable preservation effects. Attractive applications have been identified in many food areas. The present article briefly introduces the concept of hurdle technology, presents potential applications and gives details on a recently concluded study concerned with this topic and to which scientists from 11 European countries have contributed.

The spoilage and poisoning of foods by microorganisms is a problem that is not yet under adequate control, despite the range of preservation techniques available (e.g. freezing, blanching, pasteurizing and canning). In fact, the current consumer demand for more natural and fresh-like foods, which urges food manufacturers to use only mild preservation techniques (e.g. refrigeration, modified-atmosphere packaging and bioconservation), should make this problem even greater. Thus, for the benefit of food manufacturers there is a strong need for new or improved mild preservation methods that allow for the production of fresh-like, but stable and safe foods. The concept of hurdle technology is not new but addresses this need in full<sup>12</sup>.

Hurdle technology (also called combined methods, combined processes, combination preservation, combination techniques or barrier technology) advocates the deliberate combination of existing and novel preservation techniques in order to establish a series of preservation.

\*Revised version of an article published in 1994 in Voedingsmiddelentechnologie 27(21), 15–17 [In Dutch] and ALITECNA 4, 17–19 [in Portuguese].

Lothar Leistner is at the Federal Centre for Meat Research, E.C. Baumannstrasse 20, D-95326 Kulmbach, Germany. Leon G.M. Gorris (corresponding author) is at the Institute for Agrotechnological Research (ATO-DLO), Bornsesteeg 59, PO Box 17, NL-6700 AA Wageningen, The Netherlands (fax: +31-8370-12260; e-mail: L.G.M.CORRIS@ATO.AGRO.NL).

### Food preservation by hurdle technology\*

Lothar Leistner and Leon G.M. Gorris

vative factors (hurdles) that any microorganisms present should not be able to overcome  $^{13-6}$ . These hurdles may be temperature, water activity  $(a_w)$ , pH, redox potential, preservatives, and so on. It requires a certain amount of effort from a microorganism to overcome each hurdle. The 'higher' the hurdle, the greater the effort (i.e. the larger the number of organisms needed to overcome it). Some hurdles, like pasteurization, can be high for a large number of different types of microorganisms, whereas others, like salt content, have a less strong effect or the effect is limited in the range of types of microorganisms it affects.

The fact that a combination of preservative factors influences the microbial stability and safety of foods has been known for many centuries. The concept is more or less unconsciously used in many traditional foods, especially in the developing countries. It was re-invented some 15 years ago in the meat industry where the conscious employment of hurdles was found to be highly favourable for the production of shelf-stable sausages<sup>2</sup>. The concept is now ready to be introduced for use with a much wider range of food products, including fruits and vegetables, bakery products, dairy products, fish, and so on. Several novel preservative factors (e.g. gas packaging, bioconservation, bacteriocins, ultrahigh-pressure treatment, edible coatings, etc.) that specifically facilitate this development have been assessed?

Hurdle technology is a crucial concept for the mild preservation f foods, as the hurdles in a stable product concertedly control microbial spoilage and food poisoning, leaving desired fermentati n processes unaffected. Because of their concerted, sometimes synergistic effect, the individual hurdles may be set at lower intensities than would be required if only a single hurdle were All rights reserved. No part of this publication may be translated, reproduced, stored in an electronic retrieval system, published or transmitted, in any form or by any means, such as but not limited to, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the copyright where and the Publisheer, Elsevier Trends J urnals, 68 Hills Road, Cambridge, UK CB2 ILA.

Special regulations for readers in the USA. This Journal has been registered with the Copyright Clearance Center, Inc. Consent is given for copying of articles for personal or internal use, or for the personal use of Specific clients. This consent is given on the condition that the copier pays through the Copyright Clearance Specific clients. This consent is given on the condition that the copier pays through the Copyright Clearance Center the per-copy fee stated in the code on the first page of each article for copying beyond that permitted Center the per-copy fee stated in the code on the first page of each article for copying beyond that permitted by Sections 107 or 108 of the US Copyright Law. The appropriate fee should be forwarded with a copy of the first page of the article to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA to 1923, USA (tel.+1-508-750-8400; fax:+1-508-750-4744). If no code appears in an article, the author has not given broad consent to copy and permission to copy must be obtained directly from the author. This not given broad consent to other kinds of copying, such as for general distribution, resale, advertising and consent does not externed to other kinds of copying, such as for general distribution, resale, advertising and promotion purposes. Of for creating new collective works. Special written permission must be obtained from the Publisher for such copying.

Notice. No responsibility is assumed by the Publisher for any injury and/or damage to persons or property as a matter of product liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein.

The Copyright Clearance Center fee code for Trends in Food Science & Technology is 0968-0020/95/\$09.50.

Now you were the contract of t

Published by: Elsevier Trends Journals, 68 Hills Road, Cambridge, UK CB2 ILA.

Steenbock Memorial Library
Steenbock Misconsin - Madison
University of Wisconsk Drive
550 Babcock Drive
550 Babcock 1298
Madison, WI 53708-1298

used as the preservati n technique. The application of this concept has proven very successful, as an appropriate combination of hurdles achieves microbial stability and safety and also stabilizes the sensory, nutritive and economic properties of a food.

**Examples of the hurdle effect** 

A food product is microbiologically stable and safe because of the presence of a set of hurdles that is specific for the particular product, in terms of the nature and strength of their effect. Together, these hurdles keep spoilage or pathogenic microorganisms under control because these microorganisms cannot overcome ('jump over') all of the hurdles present. Examples of sets of hurdles are illustrated by Figs 1a—e. The example shown

in Fig. 1a represents a food containing six hurdles: high temperature during processing (F value), low temperature during storage (t value); low water activity (a<sub>w</sub>), acidity (pH) and low redox potential (Eh), as well as preservatives (pres.) in the product. Some of the microorganisms present can overcome a number of hurdles but none can jump over all the hurdles used together. Thus the food is stable and safe. This example is only a theoretical case, because all hurdles are depicted as having the same intensity, which is rarely the case in practice. More likely, hurdles are of different intensity, as in the second example (see Fig. 1b), where a<sub>w</sub> and preservatives are the main hurdles and storage temperature, pH and Eh are minor hurdles. If there are only a few microorganisms present at the start (see Fig. 1c), fewer different

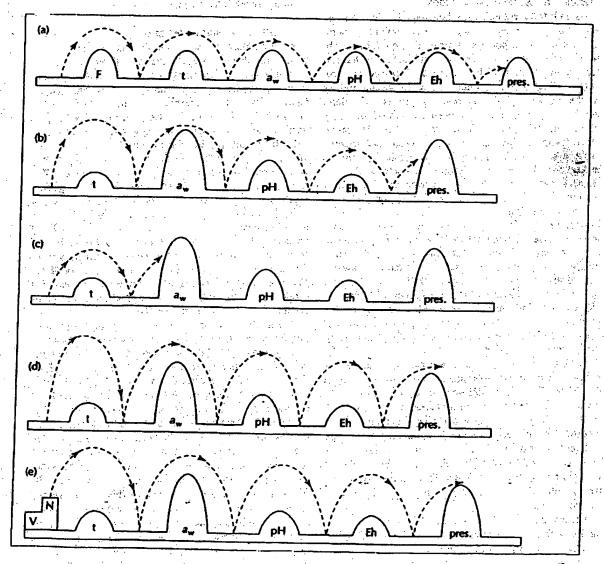


Fig. 1

Five examples of the hurdle effect used in food preservation. The individual hurdles may be encountered simultaneously or sequentially, depending on the type of hurdle and the overall processing. Symbols have the following meaning: F, heating; t, chilling:

a\_ low water activity: pH, acidification; Eh, low redox potential; pres., preservatives; V, vitamins; N, nutrients. See text for details.

hurdles microbi number bygieni suffice Fig. 1d in nutri term, s result the effect') ditional stability

Exampl Usin: ages ca ture for ility is that are cess, le in the are the of the other t cause : and fav tic acid the pro f the lower: teria de a, dec hurdle ness of in com Sausagi in othe etables the pro The lished the pro this ca: hurdles modific and ch play (F Udine, tive in and mi A ro hurdle countri

derived and ce high as

ture (.

increas

techno

this st

:s: high :Inpera- $(a_{\bullet})$ , well as : microhurdles ogether. s only a as havin practy, as in CESCIVAture, pH v micro-

different

, se.

1

Marie W. St. Cardin The state of the s hurdles or hurdles of lower intensity may achieve microbiological stability. On the other hand, if high numbers of micro organisms are present owing to poor hygienic conditions, the usual set of hurdles may not suffice to preverse spoilage or food poisoning (see Fig. 1d). The example shown in Fig. 1e is a food rich in nutrients and vitamins, which may allow for shortterm, strong growth of the microorganisms, and as a result their initial number is increased sharply ('booster effect'). In the examples shown in Figs 1d and 1e, additional or higher hurdles are needed to assure product stability.

1.16 5 15

Examples of hurdle-preserved foods

Using hurdle technology, salami-type fermented sausages can be produced that are stable at ambient temperature for extended periods of time. The microbial stability is achieved by the use of a combination of hurdles that are important in different stages of the ripening process, leading to a stable final product. Important hurdles in the early stage of the ripening process of salami are the preservatives salt and nitrite, which inhibit many of the bacteria present in the meat batter. However, other bacteria multiply, use up oxygen and thereby cause a drop in Eh, which inhibits aerobic organisms and favours the selection of lactic acid bacteria. The lactic acid bacteria then flourish, causing acidification of the product and a decrease in pH. During long ripening of the salami, the various hurdles gradually become lower: nitrite is depleted, the number of lactic acid bacteria decreases, Eh and pH increase. On the other hand, a, decreases with time, and thus becomes the main hurdle in long-ripened raw sausage4. Increased awareness of the concerted effects of the various hurdles used in combination has made the production of fermented sausages less empirical. Similar combinations of hurdles in other types of fermented foods (e.g. cheese and vegetables) are responsible for the stability and quality of the products.

The hurdle technology approach has also been established for use with non-fermented foods, for instance in the production of tortellini, an Italian pasta product. In this case, reduced a, and mild heating are the principal hurdles employed during processing, in addition to a modified atmosphere or ethanol vapour in the package and chilling of the product during storage and retail display (Ref. 8 and P. Giavedoni, PhD thesis, University of Udine, Italy, 1994). Ethanol was found to be very effective in inhibiting microbial growth, especially moulds and micrococci.

A recent survey of foods traditionally preserved using hurdle technology, conducted in 10 Latin American countries, identified some 260 different food items derived from fruit, vegetables, fish, dairy products, meat and cereals, which often had a high a, (sometimes as high as 0.97) and that were stabl at ambient temperature (25-35°C) for several months. Based on the increased knowledge of the principles underlying hurdle technology, the Latin American scientists involved in this study are now applying the concept to design shelf-

stable, innovative food preparations based on tropical and subtropical fruits (peach, pineapple, mango, papaya, etc.)10.11

An overview of combinations of hurdles that have either been studied or already employed, to date, in a range of food products is given in Table 1. In a number of recently developed food products, an almost infinite shelf life can be obtained. An example of this is canned peas marketed in the UK, in which the heat-stable bacteriocin nisin is used as an extra hurdle12. Normally, heating and pH reduction are the only two hurdles employed, but these do not suppress the growth of surviving acid-tolerant, spore-forming clostridia, which are completely inhibited by nisin.

Homeostasis and hurdle technology

An important phenomenon that is crucial with regard to hurdle technology is the so-called homeostasis of microorganisms<sup>13</sup>. Homeostasis is the constant tendency of microorganisms to maintain the stability and balance (uniformity) of their internal environment. For instance, although the pH values in different foods may be quite variable, the microorganisms living in them expend considerable effort keeping their internal pH values within very narrow limits14. In an acid food, for example, they will actively expel protons against the pressure of a passive proton influx. Another important homeostatic mechanism regulates the internal osmotic pressure (osmohomeostasis). The osmotic strength (which is inversely related to the a, of a food is a crucial physical property, which has a great effect on the ability of organisms to proliferate. Cells have to maintain a positive turgor (pressure) by keeping the osmolarity of the cytoplasm higher than that of the environment, and they often achieve this using so-called osmoprotective compounds such as proline and betaine<sup>13,15</sup>.

Preservative factors (hurdles) may disturb several or just one of the homeostatic mechanisms of microorganisms, and as a result the microorganisms will not multiply but instead remain inactive or even die13. In fact, food preservation is achieved by disturbing the homeostasis of microorganisms in foods, either temporarily or permanently, and the optimal way to do this is to deliberately disturb several of the homeostatic mechanisms simultaneously6. This means that any hurdles included in a food should affect the undesired microorganisms in several different ways, for example by affecting the cell membrane, DNA, enzymes, pH, Eh and a, homeostasis systems. This multi-targeted approach is the essence of hurdle technology a. Furthermore, this approach is often more effective than single-targeting and enables the use of hurdles of lower intensity, and thereby has less of an effect on product quality. Also, it is possibile that different hurdles in a food will not just have an additive effect on stability, but might act synergistically 1.5-7. In practical terms this could mean that it is more effective to use a combination of different preservative factors with low intensities that affect different microbial systems or act synergistically than to use a single preservative factor with a high

Fig. 1 aneously : chilling; r details.

	Contage Potesto.  Contage Critical Ham Peupper Heide-Ya packaged Critical Ham Peupper Heide Ya X X X X X X X X X X X X X X X X X X	Table 1. An overview of otherent types of hurdle-preserve	ge of	mudle-pa		d food products	<b>3</b>	ja Po	7.4 10.4		•••	) in .							
Meide 's modaged in all and all and all and all all and all all all all all all all all all al	Ham. Pepper Jim packaged using wing wing wing wing wing wing wing w		: 			•	. (*			April		See	Bre	-6					
	Kann, Pepper Jam all main  X X X X X X X X X X X X X X X X X X X	Cottag	2	Potato	A*.			7	MAP.	2 E	. B	guitan using	Page 1	<b>B</b> .4	3	is di ent	MAP.	Acidified	,
** * * * * * * * * * * * * * * * * * *	X X X X X X X X X X X X X X X X X X X	chees		orings	₹.		epper	mine.	Separate Parage		<b>w</b> e	vapour	<u></u>	<u> </u>	salmon	Pasts atte	Tage de tage	Pasteurized	723
** * * * * * * * * * * * * * * * * * *	X X X X X X X X X X X X X X X X X X X	tain cause of spoilage		, .		x 1*		54 E		••					· · · · · · · · · · · · · · · · · · ·				
* * * * * * * * * * * * * * * * * * *	X X X X X X X X X X X X X X X X X X X	licrobiological		- C	*	,	mr.		\$	• • • •						•	. 1		
× × × × × × × × × × × × × × × × × × ×	X X X X X X X X X X X X X X X X X X X	iochemical		<b>×</b>	<b>×</b>			. / <b>&gt;</b>	<b>«</b> >			•		) (1) (1) (1) (2)	×	en de Grand	ingi.	·· .	
× × × × × × × × × × × × × × × × × × ×	X X X X X X X X X X X X X X X X X X X	ysical	<u>;</u> :	· ·::.:	ile 194 1940 :	·.:		. : <b>C</b> : j <b>&gt;</b>	<		¹ :	×	×		×	×	×	×	
×× × × × × 5 *	X X X X X X X X X X X X X X X X X X X	insory					×	(44 s.)				*		ele e Televisione George	. ·	· ·			
×× × × × × × × × × × × × × × × × × × ×	X X X X X X X X X X X X X X X X X X X	pe of hurdle	÷ ,6	. · ·				· · ·	*::	· · ·		. ;				14. 1 14. 14.	:	:	
* * * * * * * * * * * * * * * * * * *	X X X X X X X X X X X X X X X X X X X	gh temperature	•	` ", <b>&gt;</b>	>	eriorio Service Transference			· ;		1 H 1					19 194 - 1			
×× × × 5 *	X X X X X X X X X X X X X X X X X X X	w temperature X		<b>t</b>	<" >	•	<	9) 9) 2)	3	×				132 733 3	1, 13 14, 140	×	×	×	
×× × 5 *	X X X X X X X X X X X X X X X X X X X	th acidity (low pH) x			É		**	>	Κ.	`: ; . <b>?</b>			•	•	(114)	×	×	×	•
×× × 5 *	X X X X X X X X X X X X X X X X X X X	v water activity (a_)		×	×			<b>C</b> :		<		>	944. Mol 1 1986		:	×	vy ** •	×	
×× × 5 *	X X X X X X X X X X X X X X X X X X X	v redox potential (Eh)					;	•	<b>×</b>			≺	3		•		×	,	
×× × 5 *	X X X X X X X X X X X X X X X X X X X	servative(s) X			×				<b>:</b>	, <b>×</b>			<	 			×	: • : 124	
×× × 5 *	X X X X X X X X X X X X X X X X X X X	mpetitive:flora			×				.*				1. . 31 . 31	٠	<b>&lt;</b> >	•		 !	7
×× × 5 *	X X X X X X X X X X X X X X X X X X X	dified gas atmosphere					· f		×	٠.		×	*		<	. ':	V2***	 	
×× × 5 *	X X X X X X X X X X X X X X X X X X X	kaging film			e A					· 9		 . : Y	•			· .	 * >		
× × 5 *	X X X X X X X X X X X X X X X X X X X	ahigh pressure	٠.,			 	×	×		· ':				· ;			<b>&lt;</b>	 	
× 5 %	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	usion	40		. · ·		×			· • •	* v.		i ti GSS. Grad	•			•	•	
× 75 *	X X X X X X X X X X X X X X X X X X X	duct origin			***		1991			· .				. <u></u> .		ne. See		·.	
* AA *	US UK Japan France, UK, UK  VS 12 1 00  C. Banis of the Campiden & Chorleywood Food Research Astociated	ditional		×	*				e d		i si Tasi Tasi	ises Es Milki				•	٠٠.	, ,	
8 CK	US UK Japan France, UK, UK USA >2	ently developed					<b>×</b>	×		: ×	. ها د آران ۲۰۲۶	/ <b>×</b>	>	<i>x 4</i> / ∴:	×;	<b>&gt;</b>	" ነር . <b></b>	. ' <b>:</b>	
8	Appen rearing, UK, UK USA  >2 cc 12 1 m C. Banits of the Campiden & Chorleywood Food Research Astroclaric	untry developed UK, US		· • · ·	. <u>.</u>	1.	· ^.	1				<b>.</b>					(ta ). <b>≺</b>	<b>X</b>	
<b>8</b>	52 cc 12 1 so G. Banits of the Campdon & Charleywood Food Research Associated	marketed in		er Dig	3		5		USA USA	<b>5</b>		urde.		<b></b> ;	IK, USA	<b>*</b>	UK USA	Europe	•
	G. Baniss of the Campden & Chorleywood Food Research Associate	if life (weeks)	•	>25	7	4	8	2	-	8		¥1 111 222	2	:	<b> </b>		y		
֡	G. Banks of the Campden & Chorleywood Food Research Associate					3									) 	147 1974 1974	 • 2€ ; 455	<b>X</b>	

intensit the obje undesir thus at extrems. Anot referred ргевеги meat p that has cessing are abl these a viabl : storage for ser preserv general becaus probab strain e various bolical SOUTCE: hurdle**become** temper

Potenti Up t for use

Box 1. Physics High t low te ionizin radioin high e pressur coating (gas pa aseptic Physic (NaCI), acids, phite, : **surface** reactio Microl Compe Miscel Monol

'A des

intensity. Moreover, in the hurdle technol gy concept, the objective is to inhibit the growth and proliferation of undesired organisms rather than to actually kill them, thus allowing for the use of hurdles that are not too extreme.

Another phenomenon of practical relevance is referred to as the autosterilization of stable, hurdlepreserved foods. In some ambient-temperature-stable meat products containing clostridia and bacilli spores that had survived the heat treatment applied during processing, it has been observed that some of these spores are able to germinate to form vegetative cells, but that these appear not to be viable and therefore die off. The viable spore count thus shows a gradual decrease during storage. The same phenomenon has been observed for several bacteria, yeasts and moulds in hurdlepreserved fruit products stored without refrigeration. A general explanation for the phenomenon might be that, because of the elevated temperature which favours and probably triggers microbial growth. Pegetative cells strain every possible repair mechanism to overcome the various hurdles present. In doing so, they become metabolically exhausted; they completely use up their energy sources and die. Thus, because of such autosterilization, hurdle-preserved foods that are microbiologically stable become even safer during storage, especially at ambient temperatures.

### Potential hurdles

Up to now, ~50 different hurdles have been identified for use in food preservation (Box 1). The most commonly

Box 1. Potential hurdles for use in the preservation of foods

### Physical hurdles:

High temperature (sterilization, pasteurization and blanching), low temperature (chilling and freezing), ultraviolet radiation, ionizing radiation, electromagnetic energy (microwave energy radiofrequency energy, oscillating magnetic field pulses and high electric field pulses), photodynamic inactivation, ultrahigh pressure, ultrasonication, packaging film (plastic, multi-layer, active coatings and edible coatings), modified-atmosphere packaging (gas packaging, vacuum, moderate vacuum and active packaging), aseptic packaging and food microstructure.

### Physicochemical hurdles:

Low water activity (a\_), low pH, low redox potential (Eh), salt (NaCh), nitrite, nitrate, carbon dioxide, oxygen, ozone, organic acids, lactic acid, lactate, acetic acid, acetate, ascorbic acid, sulphite; smoking, phosphates, glucono-ò-lactone, phenols, chelators, surface treatment agents, ethanol, propylene glycol, Maillard reaction products, spices, herbs, lactoperoxidase and lysozyme.

### Microbially derived hurdles:

Competitive flora, protective cultures, bacteriocins and antibiotics.

### Miscellaneous hurdles:

Monolaurin, free fatty acids, chitosan and chlorine.

\*A description of the various hurdles and their applications in food preservation is given by Bogh-Sørensen<sup>17</sup>

used important hurdles are high temperature, low temperature, low a, acidity, low redox potential, competitive microorganisms (e.g. lactic acid bacteria) and preservatives (e.g. nitrite, sorbate and sulphite). However, many other hurdles are of interest because of their potential for use in food preservation. Recently, a group of scientists from laboratories in 11 different European countries, sponsored by the European Union's FLAIR (Food-linked Agro-industrial Research) programme, studied the traditional and novel hurdles used in food preservation in detail, and compiled a report to document their findings?. This report gives an introduction to the application of combined processes in food preservation, presents practical examples of foods preserved by combined processes and describes various preservative factors ('hurdles') that have the potential to be exploited in food preservation. A number of relatively new hurdles are discussed in the form of mini-overviews. Among others, the emerging hurdles include ultrahigh pressure, modified-atmosphere packaging, bacteriocins and edible coatings. The report has been written to assist food processors, scientists and students who are interested in the field of hurdle technology to apply this gentle preservation system to our foods. A copy of the 120-page final report can be obtained free of charge by contacting the corresponding author.

### The future of hurdle technology

There has been increasing interest in the design and application of hurdle technology in food preservation over the past few years. It is expected that this development will proceed in the near future, especially as national and international funds have now been established that should allow for (pre-)competitive studies in this field. The Commission of the European Union, for instance, has taken up the area of combined processes as a priority theme (area 3.3.2) in the forthcoming AIR2 ['Agriculture and Agro-industry, including fisheries' (also including food technology, forestry, aquaculture and rural development)] programme that runs under the Fourth Framework initiative from 1994 to 1998.

The combination of various hurdles in the processing and storage of foods has the primary target of obtaining safe foods that are stable with respect to microbial spoilage, using as mild a treatment as possible. However, the concept of hurdle technology may also contribute to improving the organoleptic quality or total quality of foods as perceived by consumers, and developments in this respect are also expected in the near future.

### References

- Leistner, L. (1978) in Food Quality and Nutrition (Downey, W.K., ed.), pp. 553–557, Elsevier
- 2 Leistner, L., Rödel, W. and Krispien, K. (1981) in Water Activity: Influences on Food Quality (Rockland, L.B. and Stewart, G.F., eds), pp. 855–916, Academic Press
- Leistner, L. (1985) in Properties of Water in Foods in Relation to Quality and Stability (Simatos, D. and Multon, J.L., eds), pp. 309–329, Martinus Nijhoff Publishers, Dordrecht, The Netherlands
- 4 Leistner, L. (1987) in Water Activity: Theory and Applications to Fond

- (Rockland, L.B. and Beuchat, L.R., eds), pp. 295-327, Marcel Dekker
- 5 Leistner, L. (1992) Food Res. Int. 25, 151-158
- 6 Leistner, L. (1995) in New Methods of Food Preservation (Gould, G.W., ed.), pp. 1–21, Blackie
- Leistner, L. and Gorris, L.G.M., eds (1994) Food Preservation by Combined Processes (EUR 15776 EN), Commission of the European Community, Brussels, Belgium
- 8 Giavedoni, P., Rödel, W. and Dresel, J. (1994) Fleischwirtschaft 74, 639–642
- 9 Aguilera Radic, J.M., Chinile, J., Tapia de Daza, M.S., Wehl Chanes, J. and Parada Arias, E. (1990) Inventario de Alimentos de Humedad Intermedia Tradicionales de Iberoamérica, Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Biotecnologia, Mexico
- 10 Alzamora, S.M., Tapia, M.S., Argaiz, A. and Welti, J. (1993) Food Res. Int. 26, 125–130

- 11 Lopéz-Malo, A., Palou, E., Wehi, J., Corte P. and Argaiz, A. (1994) Food Res. Int. 27, 545–553
- 12 Gorris, L.C.M. and Bennik, M.H.J. (1994) Z. LebensmitteNvirtsch. 45(11), 65–71
- 13 Gould, G.W. (1988) in Homeostatic Mechanisms in Microorganisms (Whittenbury, R., Gould, G.W., Banks, J.G. and Board, R.G., eds), pp. 220–228, Bath University Press, Bath, UK
- 14 Häussinger, D., ed. (1988) pH Homeostasis: Mechanisms and Control, Academic Press
- 15 Csonka, L.N. (1989) Microbiol. Rev. 53, 121-147
- 16 Leistner, L. and Karan-Djurdjić, S. (1970) Fleischwirtschaft 50, 1547–1549.
- 17 Begh-Sørensen, L. (1994) in Food Preservation by Combined Processes (EUR 15776 EN) (Leistner, L. and Gorris, L.G.M., eds.), pp. 7–24, Commission of the European Community, Brussels, Belgium

**Review** 

### The development of process flavors

### Charles H. Manley and Sajid Ahmedi

The scientific, artistic and regulatory aspects of process flavors are reviewed. The role of the flavorist, as it relates to the creation of process flavors for commercial purposes, is discussed. An overview of the chemistry and analytical techniques used as tools for the artistic approach is also given. In addition, the development of 'building blocks' for flavor creation is discussed, and comparisons are made between the methods used for the creation of classical flavors versus process flavors. Finally, the regulations relating to the safety and labeling of these flavors are considered.

Man's interest in 'cooked' flavors started with the evolution of the human species, and man is the only representative of the animal kingdom that has established the practice of cooking food before eating it. The use of fire, and subsequently other heat sources, to render a raw material palatable is one of man's higher intellectual achievements. The creation of a 'cooked' flavor presents the flavorist with a major challenge.

Chemistry, particularly analytical and natural product chemistry, allows for the further development of our basic understanding of the components that arise during

Charles H. Manley and Sajid Ahmedi are at Takasago International Corp. (USA), Teterboro, NJ, USA (fax: +1-201-288-1692).

the cooking of foods and the mechanisms involved. Many excellent reviews covering this area of chemistry have already been published. This article will explore those areas in which chemistry can assist the flavorist in creating flavors that are developed by the use of the 'process' of cooking.

### The flavorist's approach

The flavorist's approach to flavor development is a creative one, but with a scientific foundation. Let us first review how the flavorist sets about the task of creating flavors from scratch.

The most important step is to first evaluate the target flavor in descriptive terms. A commonly used method is to describe the flavor's character in terms of its top, middle and base 'notes'. The flavorist draws upon experience gained from past work on different flavor blends. An ingredient that might be suitable for providing a certain top note may adversely affect the middle and base notes; therefore, a vast amount of experience as well as a degree of artistry are needed to effectively combine these notes to produce a well-balanced flavor.

Sensory evaluation methods may help define the flavor in terms of its attributes and strength. A small panel of sensory experts (5-8 flavorists) is needed to do this. Efforts are focused on selecting appropriate descriptive terms (usually 6-8) that relate to the character and quality of the flavor or taste.

A more in-depth evaluation may be accomplished by using analytical methods such as the extraction of volatiles, followed by their separation using gas chromatography and aroma evaluation of the separated components (olfactometry). A number of good reviews on such methods for evaluating a flavor can be found in a recent publication. By the use of these methods, the important volatile flavor components can be identified.

Once the basic formula of a flavor has been obtained using the analytical methods, the flavorist is ready to put artistry to work. The aroma components that have

Table 1

Compo

Aldehy

Furans

Furanoi

Pyrazin

Thiazol

Thioph

Polysul

\*Data ta \*1 ppb r FEMA, F GRAS, \*

been it flavorby sek synther be nee apply t The ac the cre

A dimethor that re terials essenti sences have trence vinvolvo of corr blocks likely flavor yet the

Develo \*\* In th refy bc of ches mixtur main d a proc flavors of the referre The fit relates , btoce: any ot food r. proces:

### EXTENDING THE SHELF-LIFE OF CHILLED READY MEALS

### ROBERT SHAW

Campden & Chorleywood Food Research Association (CCFRA), Chipping Campden, Gloucestershire, GL55.6LD, UK

The growth in sales volume and variety of chilled, short shelf-life, ready-to-eat or reheat ready meals (mostly meat based) has been a notable feature in the UK food retailing scene over the last 10 years. These products now represent a significant sector of meat consumption. However, the safe production of such products, and the achievement of even the short product lives currently claimed, rests heavily on hygienic production (the 'high risk' concept) and on strict temperature control throughout production, distribution, display and sale. The practical application of these and other considerations to safety and shelf-life is described in this paper, before going on to consider ways of extending life. These include extending factory buffer stock holding time by use of 'deep chill', or by freezing followed by carefully managed defrosting. Extension of shelf-life during distribution and display can be obtained by post-pack pasteurising of the product, either by conventional means or by microwave, but the addition to shelf-life which can be achieved is limited by the hazard represented by potential presence of strains of Clostridium botu-linum in sealed packs which typically have little or no headspace.

Keywords: chilled, ready meals, safety, shelf-life

### INTRODUCTION

The UK is probably one of the most active and dynamic markets in the world for new food and drink products. Products Intelligence (PI) at Campden & Chorleywood Food Research Association (CCFRA) seeks to identify and report all new products found in UK supermarkets. Even in an economic recession, the rate of introduction of new products has continued to increase rapidly, as shown in Table 1.

TABLE 1

	· (S		CTS IDENTIFIED OUCT INTELLIGE		
Year		Meat-based	Poultry-based	All sectors	,
1990		417	189	2933	
1991		537	305	3233	
1992	•	548	345	3823	
1993	•	537	362	4525	
1994		525	379	4815	
1995		586	371	4596	

From these figures it can be seen that following rapid growth in the UK in meat- and poultry-based products in 1990-1992 which formed part of the rapid growth f all new food products during this period, the more recent period f 1993 to date has seen a levelling-off of growth overall, although the number of meat-based new products has continued t increase with 1995 recording the highest figure yet in this sector.

A major contribution to the achievement of these figures is made by the retailers. In the UK, the major supermarket chains dominate the food industry to a greater degree than elsewhere. The retailers appear to have an almost insatiable appetite for new products, and the outstanding profitability of this sector suggests this is a well-founded policy. The standard bearer for many years was Marks and Spencer, comparatively small in food volume terms but a major influence in terms of quality and innovation. Especially since the mid-1980s, other UK retailers have sought successfully to emulate the standards established by Marks and Spencer. Consequently, as Table 2 shows the UK carry the retailer's own label as opposed to a manufacturer's brand, and it is expected that retailer.

### TABLE 2

	Manufacturer's brands	Retailer's brands	Total	
Frozen	347	232	579	
Chilled	481	1695	2176	
Ambient stable	1045	796	1841	

These figures show that from a position where new products under manufacturers' brands and under retailers' brands were almost equal in numbers in 1992, by the end of 1995 retailers were well ahead of manufacturers, especially in the chilled foods market, which is dominated by retailers' brands in the UK. Meat-based chilled ready meals are almost exclusively the province of retailers' brands.

Sales of chilled food have increased almost threefold in the six years 1986 to 1991 (EIU Retail Business, 1992). This growth came mainly from pizzas, pasta products, pre-packaged (green) salads, and ready meals, with ready meals by some way the largest contributor. Sales of chilled ready meals, adjusted for inflation, increased from £115m in 1986 to £244m in 1991 (ibid.).

Much of this growth in chilled ready meals came from the expansion into this sector of supermarket chains other than Marks and Spencer. In 1985, the year Tesco went into chilled ready meals, it is estimated Marks and Spencer had in excess of 95% of the market for these products, which that company calls 'recipe dishes' (for the purposes of this paper the expressions 'recipe dish' and 'ready meal' can be taken as synonymous). Since then, Tesco and other major supermarkets (J. Sainsbury, Waitrose, Asda, Safeway) have increased their share of the market for chilled ready meals. By 1991, the share of Marks and Spencer had fallen to 55%, although their volume had increased in a growing market, and the assessment of PI-CCFRA is that Marks and Spencer continues to lead the way in terms of innovation and quality, although their lead over other retailers is narrowing. The contribution made by 'brands'

(manufacturers' brands) has never been large and proportionally is falling (6% in 1991) (ibid.).

The majority of chilled ready meals are meat based r contain poultry. They now form an outlet for meat raw material in the UK of considerable significance, especially important because the meat required needs almost invariably t be of the highest quality, and represent the greatest opportunity to achieve added value for the meat processor and meat products' manufacturer. Sales volume of meat- and poultry-based chilled ready meals has continued to grow since 1993, confirming the importance of this group of products in the meat products sector.

These chilled ready meals present the consumer with the opportunity to serve in the home meals of the quality normally only to be found in good restaurants, offering cuisine from around the world, the leading varieties being pasta-based/Italian (23%), traditional British (20%), Indian (19%), and Oriental (15%), with Mexican and cuisine of other nationalities and regions showing significant growth (ibid.).

### PRODUCTION OF CHILLED READY MEALS

The production of cooked ready meals is essentially a cook-chill operation. In Fig. 1 is shown the sequence in a typical operation where the meal components are cooked (each for a time and by a method optimal for that component), cooled, then cold assembled under high-risk conditions.

### FIGURE 1

### FLOW CHART OF COOKED MEAT PRODUCTS MANUFACTURE

- · Prepare raw materials and recipe
- Cook
- Cool
- Hold chilled
- Assemble
- Seal packaging
- · Sleeve, check-weigh, metal detect, price date
- Post-pack re-cool to 0°C
- Tray up/boxing
- Despatch <5°C</li>

There are variations on the routine shown here. For instance, some products (not many) lend themselves to filling hot from the cooker into the final packaging form; because of the inevitable delay between the first and the last being filled, and the need to keep the product hot until the production run is complete, this can only be applied to products (such as some 'one-shot' minced meat in sauce products) which are relatively tolerant to extended hot holding. In some cases, the concept of sous-vide, where the product is cooked and cooled in the sealed pack in which it is sold, may be applied, although in general in the UK, sous-vide is of more relevance to the catering market than to retail trade.

It should also be noted that in some cases ingredients are brought in ready cooked, e.g. canned ingredients. Given suitable precautions (can cleaning, sanitiser dip), cans may be taken into the high-risk zone, opened, and the contents used as cold-fill components at the product make-up stage.

Common, however, to all these methods of production of chilled ready meals, and a characteristic of

the genre, is the fact that consumer safety and product keepability depend on the preventative approach of strict control, and the anticipation and elimination of hazard. The essential components of this approach are: a) barriers t contamination, b) temperature control, c) effective cooking, d) rapid cooling, e) microbiological quality of raw materials and finally f) hazard analysis critical control point (HACCP).

Before going on to consider ways of extending the shelf-life of chilled ready meals, it is essential to ensure all necessary steps have been taken for these products to be routinely manufactured in such a way that 'normal' shelf-lives can be achieved with safety - typically, these products are marked with a 'display until' date five or six days from the day of cooking or of cold assembly, with a 'use by' date for the consumer one or two days later. In the case of a few simple one-shot hot-fill products, the 'display until' life may be extended to eight days. As stated, the first requirement on the manufacturer is that even these short shelf-lives can be achieved safely and with uniformly good product quality at the point of consumption.

In all cases, the declared shelf-life assumes storage, distribution and sale at a temperature not exceeding 5°C, which was demanded of suppliers to Marks and Spencer some years before it became a UK legal requirement for this type of product in the Food Hygiene Amendment Regulations of 1990 and 1991. Let us consider each of the essential components of product safety and keepability, listed above, in turn.

### Barriers to contamination

These represent the essential philosophy of safe chilled ready meal production, which is preventative as opposed to use of preservation techniques (such as chemical preservatives, low pH, reduced water activity, freezing or additional heat). These 'barriers' are built up around a production area which is designated 'high risk' (or high care). Only within the high-risk area is cooked food, which is vulnerable to contamination, exposed to handling and contact. Food enters the high-risk zone hot immediately after completion of cooking and does not leave until it is wrapped in a way which excludes contamination. The barriers around the high-risk area are of various types, including:

- Physical: walls to exclude unauthorised people and the entry of any potential hazards, including pests.
- Heat: all raw materials must pass through an effective cooking procedure at the point of entry.
- Sanitiser dip: as mentioned earlier, in some cases pre-cooked material, in cans or similar, may enter via a sanitiser dip.
- For people: rigorously enforced changing room and personal hygiene procedures, plus health screening. For suggested changing room procedures, see Thorpe, (1992). Training and motivation of staff are essential features of a successful chilled meals operation.
- For air: micro-filtration of incoming ventilation air to exclude airborne microorganisms, plus air in the high-risk area maintained at a positive pressure to preclude the ingress of draughts and dust.
- Drains and floors: falls and traps designed to carry waste and wash water always away from and not into the high-risk area.
- High standards of area hygiene with carefully managed 'clean as you go' (avoiding aerosols and scatter contamination) and thorough cleaning and drying of floors, walls, ceilings, drains and ducts outside production hours; plus a well established cycle of washing and sanitising all utensils, food containers and machinery.
- Hygienic design of all plant and premises to eliminate niches and traps for bacterial and mould growth.

### Temperature control

Product is held as close to 0°C as possible without freezing. The production w rking area will be air conditioned and refrigerated - normally t around 8°C. This temperature is a compromise between the requirements of the work force for comfort and efficiency (8°C is acceptable in the absence of draughts); the need to avoid excessive temperature rise in the product; and, most importantly, to keep contact surfaces cool so that any bacterial growth on such surfaces will be slow.

It is also important to control relative humidity in high-risk working areas and keep dampness to a minimum; puddles, condensate on surfaces, and general wetness are to be avoided because they offer a habitat to *Listeria monocytogenes*.

After packing, it is desirable to use forced air to re-cool the product to around 1°C before it passes on to distribution. During the distribution phase - which may include outer packaging and batching, despatch, transport, depot sorting, further transport, back-of-store receipt and retail display - the temperature of the product must be kept throughout no higher than 5°C (and preferably cooler, but without freezing). The integrity of the chill chain can be checked with miniature data loggers which simulate the product and can be used to integrate the effect of time and temperature on spoilage and food poisoning microorganisms. This assists the manufacturer in determining the declared shelf-life, which is normally taken as time from cooking to consumption. The date mark on the pack makes a vital contribution to the safety and quality of the product.

### Effective cooking

The cooking process must be controlled and monitored to ensure the largest pieces of meat, fish or poultry are cooked to a minimum of 70°C achieved for two min., or the equivalent (e.g. 65°C for 10 min. or 75°C for 30 s).

### Rapid cooling

Cooling should be as rapid as possible, and is usually achieved by blowing air at the optimum velocity (which has to be established by the manufacturer) across stainless steel trays containing product filled to a depth sufficiently shallow to promote rapid cooling. There are various definitions in regulations and codes of practice which seek to define target rates of cooling, but typically cooling to below 10°C in two hours is regarded as satisfactory.

### Microbiological quality of raw materials

The demands of quality require the freshest raw materials, in general precluding levels of vegetative forms of microorganisms in sufficient number to result in significant survival after cooking. High content of heat resistant spores must be avoided. Herbs and spices represent a particular hazard in this respect. The practicalities of daily production of a large catalogue of chilled ready meals using fresh ingredients demand a high level of efficiency and professionalism from buyers, quality managers and logistics staff.

### Hazard analysis critical control point (HACCP)

This philosophy is inherent in safe production of chilled ready meals. Reference should be made to the appropriate Campden manual (Leaper, 1992).

Attention t detail and to all the points covered above is, as stated, necessary to ensure the routine achievement of safe shelf-life, and indeed may with experience allow the extension of declared life by one reven two days - this seemingly short period of time can be very important in commercial terms.

Beyond that, there are some possibilities for increasing the life of these cook-chill cold-assembly retail recipe dishes in terms of adding factory storage time whilst not losing time for distribution and display. Some products lend themselves to storage at 0 to -2°C ('deep chill') for up to perhaps three days under strictly controlled conditions in the factory prior to issue. Rather fewer products are suitable for frozen storage where the finished product, wrapped and ready for sale in distribution trays or boxes, is rapidly frozen to -30°C or below, held at that temperature for several weeks, then thawed out prior to chill distribution and sale under conditions which require a considerable degree of technical sophistication and know-how to preserve the fresh quality of the product and the packaging.

Once out of the factory, safe shelf-life of such chilled recipes is limited by microbiological consideration - the growth of spoilage organism and, if present, of pathogens, especially in the event of temperature abuse, in particular by the retail purchaser. The problem in the main is represented by contamination during assembly and packing; although survival of vegetative forms (in the event of high initial loads) and of spores after cooking in the factory can play a part. Bacteria, including those from out-growing spores, can be destroyed by subjecting the finished pack to pasteurising - post-pack pasteurising. This inevitably has some effect on quality and as a process for ready meals is not widely practised in the UK, although said to be found fairly widely in France and elsewhere on the continent of Europe where the retailing pattern demands a longer shelf-life. Post-pack pasteurising is generally carried out under over pressure in an end-loading retort, but in-line microwave processing has been used for this purpose. Post-pack pasteurising should be regarded as an adjunct to, not a replacement for, all the other essentials for chilled recipe dish production. By this means, shelf-lives of 21 to 42 days at <5°C have been claimed.

However, more recently in the UK, the Government's Advisory Committee on the Microbiological Safety of Foods (1992) has recommended that chilled foods with an assigned shelf-life of more than 10 days should contain one or more controlling factors, at levels to prevent the growth and toxin production by strains of Clostridium borulinum. As the processing of most chilled recipe dishes does not include such factors, this would appear to restrict their shelf-life to 10 days. Pasteurisation, which typically achieves 70°C for a minimum of two min. in the product, would not be regarded as an adequate factor. In addition, the CCFRA Code of Practice for Vacuum and Modified Atmosphere Packed Chilled Foods (1996) contains amongst other things, guidelines for extended factory chill storage of VP and MAP products at below 3-5°C

### CONCLUSIONS

### What has been achieved?

Thanks to the driving force supplied by the supermarket retailers, chilled ready meals of high quality are now a significant market sector amongst meat-based products in the UK. A sound understanding has been achieved as to how these products can be produced safely to a commercially acceptable, albeit short,

chilled shelf-life. The technology is based on the philosophies of prevention rather than preservatives, high-risk manufacture and HACCP.

### What has been neglected?

Very little. However, the business of chilled ready meal production could come under threat from its very success, which may bring into the market producers who lack the necessary skills, facilities and expertise vital to the safe production of these types of products. This problem is minimised by the fact that most chilled meals are sold under the supermarkets' own labels, and these retailers have both the know-how and an overriding concern to ensure safe production and hence their good reputation.

### What needs to be done?

An ever-improving understanding of the microbiological aspects of the operation, together with finding ways of applying post-pack pasteurisation without excessively degrading product quality, will allow a reduction in costs (less frequent manufacture, less wastage) and extended distribution (throughout Europe). However, opportunities for extending shelf-life will be restrained by the current view of the hazard represented by Clostridium botulinum. This restraint might be eased by further research into the characteristics of this microorganism.

### REFERENCES

Advisory Committee on Microbiological Safety of Foods, Report on Vacuum Packaging and Associated Processes, HMSO, P.O.Box 276, London SW8 5DT, UK, 1992.

Code of Practice for the Manufacture of Vacuum and Modified Atmosphere Packaged Chilled Foods with particular regards to the risks of botulism, Campden and Chorleywood Food Research Association, Chipping Campden, Glos., GL55 6LD, UK, 1996.

EIU Retail Business No. 410, April 1992. The Economist Intelligence Unit.

HACCP - a practical guide. (Ed.) Leaper, S., Technical Manual No. 38, Campden Food and Drink Res. Ass., Chipping Campden, Glos, GL55 6LD.

Thorpe, R.H., 1992. Hygienic design considerations for chilled food plants. In: (Eds.) Dennis, C., Stringer, M.F., Chilled Foods: A Comprehensive Guide. Ellis Horwood, London, p 343-364.

### RESUMEN

El crecimiento en volumen de ventas y variedad de las comidas enfriadas, de vida útil limitada, listas para comer o tras recalentamiento (en su mayoría con carne) ha sido un rasgo notable en el sector alimentario minorista británico durante los últimos 10 años. Estos productos representan ahora un sector significativo del consumo de carne. Sin embargo la producción segura de tales productos, y el logro incluso de las vidas de producto reducidas reclamadas actualmente, se basa considerablemente en la producción higiénica (el concepto 'riesgo elevado') y en un control estricto de temperatura durante la producción, distribución, exhibición y venta. La aplicación práctica de éstas y otras observaciones a la seguridad y la vida útil es descrita en este trabajo, antes de seguir considerando formas de prolongar la vida útil. Éstas incluyen la prolongación del tiempo de mantenimiento del stock en la fábrica,

que se extiende mediante el uso de una 'refrigeración intensa', o congelación seguidos por una cuidadosa descongelación. La extensión de la vida útil durante la distribución y exp sición puede ser obtenida p r la pasteurización posterior del envase de producto, bien por medi convencional o por microondas, pero el aumento de la vida útil que se puede conseguir es limitado por el peligro que representa la presencia potencial de cepas de Clostridium botulinum en envases sellados que tienen poco o ningún espacio de cabeza.

### RIASSUNTO

L'aumento del volume delle vendite e della varietà dei piatti freddi, a breve conservazione, precotti (pronti da consumarsi) o precotti da consumarsi dopo riscaldamento (prevalentemente a base di carne) ha costituito un importante aspetto del panorama commerciale al dettaglio in UK nel corso degli ultimi dieci anni. Questi prodotti costituiscono oggi una quota importante del consumo di carne. Tuttavia la corretta produzione di questi alimenti ed il raggiungimento delle seppur brevi vite commerciali attualmente richieste poggia sostanzialmente sull'igiene (concetto di 'alto rischio') e sull'assoluto rispetto delle temperature previste durante la produzione, la distribuzione, l'esposizione e la vendita. In questa presentazione viene descritta l'applicazione di queste e di altre considerazioni alla sanità ed alla vita commerciale, prima di illustrare alcuni dei modi per allungare la vita commerciale dei prodotti. Questi includono un prolungamento del tempo di stoccaggio industriare mediante un intenso raffreddamento o mediante congelamento seguito da scongelamento accurato. Un certo prolungamento della vita commerciale durante la distribuzione e l'esposizione può essere ottenuto mediante pastorizzazione del prodotto confezionato, sia con sistemi convenzionali che con il forno a microonde. Tuttavia si può ottenere solo un modesto incremento della conservabilità a causa della potenziale presenza di ceppi di Clostridium botulinum nelle confezioni chiuse ermeticamente, che di solito hanno uno spazio di testa assente o di minime proporzioni.

### RÉSUMÉ

Au cours des dix dernières années, on a constaté au Royaume Uni un accroissement notable de la variété et des volumes vendus, pour les repas réfrigérés à courte durée de vie (souvent à base de viande), prêt à consommer ou prêt à réchauffer. Ces produits représentent maintenant un secteur notable de la consommation de viande. Cependant, la production de ces produits et leur conservation, même pour une courte période, repose essentiellement sur une fabrication hygiénique et sur un contrôle très strict de la température tout au long de la chaîne: production, distribution, présentation et vente. Les applications pratiques ainsi que les considérations concernant la sécurité et la durée de vie sont décrites dans cette présentation avant que ne soient présentés les différents moyens d'allonger la durée de vie. Ceuxci incluent la possibilité d'allonger le stockage au cours de la fabrication en utilisant le refroidissement rapide, ou par une congélation suivie d'une décongélation bien maîtrisée. L'allongement de la durée de vie, pendant la distribution et pendant la vente, peut être obtenu par une pasteurisation après emballage du produit, soit par des procédés conventionnels soit par utilisation de micro-ondes, mais l'allongement de la conservation est limité par le risque présenté par la présence de Clostridium bosulinum dans des emballages sous vide, qui sont donc dans des conditions anaérobies.

### KURZFASSUNG

Di Zunahme des Umsatzvolumens und der Mannigfaltigkeit von gekühlten, beschränkt haltbaren, direkt oder nach Aufwärmen zu verzehrenden Fertiggerichten (meistens auf Fleischbasis) war in den letzten 10 Jahren in der UK Lebensmitteldetailbranche sehr ansehnlich. Diese Produkte bilden heute einen bedeutsamen Teil des Fleischverbrauchs. Die zuverlässige Produktion solcher Produkte und das Erreichen von selbst der kurzen Haltbarkeit, die üblicherweise verlangt wird, beruht jedoch stark auf einer hygienischen Herstellung (das 'Hochrisiko' Konzept) und einer strikten Temperaturbeherrschung während der gesamten Produktion, Verteilung, Auslage und dem Verkauf. Die praktische Anwendung dieser und anderer Betrachtungen bezüglich Sicherheit und Haltbarkeitsdauer wird in diesem Beitrag beschrieben bevor Wege zur Haltbarkeitsverlängerung erwogen werden. Diese umfassen die Verlängerung der Lagerdauer des Betriebspuffervorrates durch Anwendung von 'tiefer Kühlung' oder durch Einfrieren mit nachfolgendem sorgfältig durchgeführtem Auftauen. Eine Verlängerung der Haltbarkeitsdauer während des Vertriebs und der Auslage kann erreicht werden durch eine Pasteurisierung des Produktes nach dem Verpacken, entweder mit konventionellen Methoden oder durch Mikrowellen. Die erreichbare zusätzliche Verlängerung der Haltbarkeitsdauer wird jedoch begrenzt durch das Risiko einer möglichen Anwesenheit von Stämmen von Clostridium botulinum in den hermetisch geschlossenen Packungen, die üblicherweise nur einen kleinen oder keinen Kopfraum haben.

### MEAT QUALITY AND MEAT PACKAGING

EDITED BY
SANDY A. TAYLOR, ANTONIO RAIMUNDO,
MAURIZIO SEVERINI AND FRANS J.M. SMULDERS

BRITISH LIBRARY DOCUMENT SUPPLY CENTRE

24 JUN 1998

98/12505



1996

# New Methods of Food Preservation

Edited by

G.W. GOULD Unilever Research Laboratory Bedford



BLACKIE ACADEMIC & PROFESSIONAL
An Imprint of Chapman & Hall
London · Glasgow · Weinheim · New York · Tokyo · Melbourne · Madras

Blackie Academic and Professional, an imprint of Chapman & Hall Wester Cleddens Road, Bishopbriggs, Glasgow G64 2NZ Published by

Blackie Academic & Professional, Wester Cleddens Road, Bishopbriggs, Chapman & Hall, 2-6 Boundary Row, London SE18HN, UK Glasgow G64 2NZ, UK Chapman & Hall GmbH, Pappelallee 3, 69469 Weinheim, Germany

Chapman & Hall USA, One Penn Plaza, 41st Floor, New York NY 10119,

Chapman & Hall Japan, ITP-Japan, Kyowa Building, 3F, 2-2-1 Hirakawacho, Chiyoda-ku, Tokyo 102, Japan DA Book (Aust.) Pty Ltd, 648 Whitehorse Road, Mitcham 3132, Victoria,

Chapment & Hall Yadia, R. Seshadri, 32 Second Main Road, CIT Bast,

First edition 1995

ang - bury

Typeset in 10/12pc Times by Acorn Bookwork, Salisbury, Wiltshire Printed in Great Britain by Hartnolls Ltd., Bodmin, Comwall. © 1995 Chapman & Hall

UK. Enquiries concerning reproduction outside the terms stated here should be sent to the publishers at the Glasgow address printed on this page. transmitted, in any form or by any means, without the prior permission in or criticism or review, as permitted under the UK Copyright Designs and writing of the publishers, or in the case of reprographic reproduction only issued by the appropriate Reproduction Rights Organization outside the Apart from any fair dealing for the purposes of research or private study Licensing Agency in the UK, or in accordance with the terms of licences Patents Act, 1988, this publication may not be reproduced, stored, or in accordance with the terms of the licences issued by the Copyright

to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be The publisher makes no representations, express or implied, with regard

A catalogue record for this book is available from the British Library Library of Congress Catalog Card Number: 94-79139

University of teleponetin - Madison Shoonbook Momorial Library Meriton, WI 53708-1293 530 Bat Jock Drive

©Printed on acid-free text paper, manufactured in accordance with ANSIMISO 239.48-1992 (Permanence of Paper)

4 %

43N 8909

Preface

The major techniques employed for food preservation have a long history of use. They include chilling; freezing; drying; curing; conserving; fermenting or otherwise acidifying; the addition of preservatives; heatpasteurisation and sterilisation.

or 'hurdle' methods, vacuum- and modified atmosphere-packaging, and Newer techniques more-or-less derived from these traditional procedures include the successful application of combination. preservation continuous sterilisation coupled to aseptic packaging. More innovative techniques, such as the use of ionising radiation, are increasingly being employed.

At the same time, there is a reawakening of interest in even more radical requirements for foods that are higher in quality, so less severely processed; more natural, so less heavily preserved; nutritionally healthier, so approaches. The reasons for this derive principally from consumers' containing less salts, sugars and fats; and, with respect to food poisoning, with retained, or preferably improved, assurance of safety.

Some of these more radical approaches are chemically-based, some logies whilst others are completely new. They include, for example, a heating, and with consequent minimal damage to product quality; the use biological and some physical. A number of them build on current technoand safely used; new applications of modified atmosphere packaging; use lysozyme, lactoperoxidase, lactoferrin), plant-derived (e.g. herb, spice and other plant extracts) and microorganism-derived (e.g. bacteriocins); new and improved means for the accurate delivery of heat to foods (e.g. by microwaves, by ohmic heating) so as to achieve the minimal processes necessary to ensure stability and safety; the use of high hydrostatic pressures to inactivate microorgar is in foods without the need for substantial continual widening of the combination procedures that can be effectively of high voltage electric pulses for similar purposes; the direct and synergistic application of ultrasonic radiation to pasteurise and sterilise foods with the minimal application of heat; innovative food surface decontamination of naturally occurring antimicrobials that are animal-derived (e.g. procedures aimed at greatly improving the safety of some foods of animal origin; radically new approaches to aseptic processing.

progress already made and also to indicate potential for the future. It is This book covers these major trends in such a way as to summarise irrected at food companies involved in production, distribution and sale.

\gt

CONTENTS	

<b>o</b> .	φ <u>Ω</u>	Advances and potential for assigning processing  D. ROSE	
	13.1	Aseptic technology	
	13.2	Regulatory effects	
	13.3	Aspects of food manufacturing practice 13.3.1 Scheduled processes	
-	13.4	6	
	13.5	Design and development	
		13.5.2 Food process	
		13.5.3 Non-food contact surfaces	
	٠	13.5.4 Decontamination of packaging	
	13.6	Commissioning tests	
	13.7	Manufacturing directive	•
	13.8	8	
		15.6.1 Duk packagug 13.8.2 Commodity, added value or niche product?	
	13.9	폏	
	References	nces	
₹.	Adv	Advances in modified atmosphere packaging	
	A.R.	R. DAVIES	
	14.1	<b>3</b> .	
	14.2	14.1.1 Role of gases Market status and potential	
	14.3	Microbiology of MAP	
		14.3.1 Microbial spoilage 14.3.2 Microbial safety	
	;	- 1	
	4.4	Developments in MAT 14'4.1 Intelligent packaging	
	· .		
	:	٠.	
		14.4.4 Fackaging nims/equipment	
	14.5	` ₹	
	Ackr	- indiament	

### Overview

283

## G.W. GOULD

### Introduction

The major technologies that are employed to preserve the quality and microbiological safety of foods include:

- procedures that prevent the access of microorganisms to foods in the first place;
- (ii) procedures that inactivate them should they nevertheless have gained access;
- (iii) procedures that prevent or slow down their growth should they have gained access and not been inactivated.

ğ

Whilst the currently used traditional preservation procedures continue to act in one of these three ways, there has recently been a reawakening of interest in the modification of these technologies, mainly in the direction of reducing the severity of the more extreme techniques. These modifications are being sought primarily to improve the quality of food products, and principally in order to meet the requirements of consumers through the avoidance of the extreme use of any single technique. In addition to the modified techniques, but with the same objective of improving food quality, radically new techniques are also being researched and applied. For both modified and the new techniques it is imperative that they deliver not only the promised improvements in quality but also an equivalent, or preferably an enhanced, level of safety compared with the procedures that they replace.

References

For these reasons, the summaries of new and improved methods of preservation in the following chapters are opportune.

## Consumer requirements

Consumers' requirements constantly change and, with respect to foods in recent years, have encompassed desires for foods that are convenient to store and use and yet have higher quality, are 'fresher', 'more natural' and 'healthier' than hitherto. At the same time, increased awareness of the risks of food poisoning has ensured that a high degree of assurance, and indeed improvement, of safety are perceived as key requirements as well.

Table 1 Consumer requirements impacting on the development of preservation technologies

Lower levels of salt, fats and sugars Blimination of food-poisonoing microorganisms from the most often contaminated foods and More use of natural preservation systems better flavour, texture and appearance Less use of artificial additives minimal freeze damage minimal over-heating satisfactory shelf-life less intensive heating **Nutritionally healthier** Less severe processing Means of achievemen Major requirement More convenience ease of storage raw materials ligher quality More natural resher

Table 1 summarises these consumer requirements and indicates some of the likely means for satisfying them. It will be apparent that a number of these means of achievement (e.g. less heat, less salt, less use of preservatives) may actually lead to a loss in the intrinsic preservation and safety of a food. It is therefore important that the new and improved technologies effectively build back the preservation that may otherwise be lost.

## Existing technologies

The existing technologies for food preservation are summarised in Table 2. Few of these act primarily by restricting the access of microorganisms to foods (item (i) above) except at the terminal phase of production of thermally processed foods, and in the sense that packaging restricts access.

There are more procedures that act via inactivation (item (ii) above) but still, considering the tonnages of foods treated, only heat is used substantially.

Turning to procedures that slow down or prevent the growth of microorganisms in foods (item (iii) above) there are many more procedures available f r use, including those that rely on control of the environment (e.g. temperature control), those that result from particular methods of processing (e.g. microstructure control) and those that depend on the intrinsic properties built in to particular formulated foods (e.g. control by the adjustment of water activity or pH value).

### OVERVIEW

Table 2 Major existing and new technologies for food preservation

Restriction of access of microorganisms to products
Aseptic packaging of thermally processed foods
Packaging
Inactivation of microorganisms in products
Heat pasteurisation and sterilisation
Indiang radiation as terrilisation
Addition of enzymes (e.g. lysozyme)
Application of high hydrostatic pressure

Slowing down or prevention of growth of microorganisms in products
Lowered temperature-chilling and freezing
Reduced water activity-curing, conserving, drying
Acidification
Fermentation
Vacuum and modified atmosphere packaging
Addition of preservatives

Electric shock treatments

Microstructure control in water-in-oil emulsions

It is against this background that the new and improved techniques are being developed.

## New and improved techniques

With respect to the procedures that restrict the access of microorganisms to foods, the employment of aseptic packaging techniques for thermally processed foods has expanded greatly in recent years, both in the numbers of applications and in the numbers of alternative techniques that are commercially available (chapter 13).

With respect to the improvement of techniques for the *inactivation* of microorganisms in foods, most effort and new application has concerned thermal processing. A particular aim has been to minimise damage to product quality. This is being pursued in two, often complementary, ways. Firstly by the wider application of more high temperature—short time processing, with associated aseptic packaging where relevant (chapter 13). Secondly, by delivering heat in new ways, e.g. by microwaves (chapter 6) or by electrical resistance ('ohmic') heating of foods (chapter 10), which allow better control of heat delivery and minimise the over-cooking that commonly occurs in more conventional thermal processes. An important safety consideration that must be borne in mind is the overall reduction in total heat delivery to foods that will result from the wider application of these techniques, as target Fo values are more and more tightly achieved.

The use of ionising radiation to preserve foods or to eradicate pathogens from them, is already well established. In addition to its value as a preservation technique, it offers a very effective route for the reduction in

food poisoning, e.g. via the irradiation of the often Salmonella- and Campylobacter-contaminated foods such as poultry and other foods of (chapter 5), negative consumer reaction in many countries holds back its animal origin. Whilst the use of radiation continues to grow worldwide

difficult to control by both these procedures, so that their use for the which spores are not a problem because they are inhibited by the intrinsic Radically new procedures for the inactivation of microorganisms in foods include two other physical procedures that offer alternatives to heat: the use of high hydrostatic pressure (chapters 7 and 8) and the use of high voltage electric pulses (chapter 11). Both techniques are highly effective in inactivating vegetative cells of bacteria, yeasts and filamentous fungi, at pressures and at voltage gradients that are compatible with the retention of high quality in some foodstuffs. However, bacterial spores remain more preservation of foods other than relatively short shelf-life or products in properties of the food (e.g. low pH or low water activity) must await further research.

Finally, concerning novel inactivation procedures, the effectiveness of that has shown that its efficacy can be enhanced by the simultaneous ultrasonic radiation in inactivating the vegetative forms of microorganisms application of (relatively low) hydrostatic pressure is leading to a rehas been well known for many years. However, the recent research work evaluation of its potential as a food preservation aid (chapter 9)

which are known to be potentially contaminated with enteric pathogens (chapter 12): In many countries, unacceptably high levels of enteric infection in the human population still occur, and the situation is getting worse rather than getting better. Many food microbiologists have come to realise that although improved hygiene education and the application of Hazard Analysis and Critical Control Point techniques etc. may all help to improve food poisoning statistics, a major reduction will only be achieved if such new elimination techniques are employed. If the organisms of concern did not enter the home or the catering establishment etc. in the first place, then the momentary lapses of hygiene that will always occur, at some A particularly important new inactivation technique has resulted from the development of surface decontamination procedures that can be applied to meat and poultry carcasses, and to other animal-derived foods frequency or other, would be of little consequence.

are traditional and indigenous to different parts of the world. It has also techniques or 'hurdle technology' (chapter 1). This has been supported by and safety of an en rmous number of combination-preserved foods that been supported by the beginning of an understanding of how many of these With respect to procedures that slow down or prevent the growth of microorganisms in foods, major successes have been seen, and new applications are steadily being made, in the use of 'combination preservation' a greatly improved understanding of the principles underlying the stability

OVERVIEW

χ̈́

combination procedures act at the cellular level, which often seems to that are fundamental to the reaction of microorganisms to the stresses to involve 'multitarget' interference with the various homeostatic mechanisms which the food technologist exposes them in foods (chapter 1),

extension of the high quality shelf-life of certain chill-stored foods. It considering its wide use, it is surprising that a full understanding of how modified atmospheres (particularly the carbon dioxide component that aging has grown rapidly in use in some countries, particularly for the remains, however, little used in other countries (chapter 14). Again, most of them contain) exert their inhibitory effects at the level of cell biochemistry have not yet been worked out. Elucidation of the mechan-Though still a relatively new technology, modified atmosphere packisms of action could lead to improved means for effective application.

To some extent, interest in naturally occurring antimicrobial systems has However, the substantial research efforts underway on animal-derived chapter 3), plant-derived (chapter 4) and microorganism-derived antimicrobial systems (chapter 2), are demonstrating the efficacy of a wide range of natural mechanisms, many of which have potential for use in food preservation. So far, few such natural systems have been included as components in combination studies, i.e. as additional 'hurdles'. This is a pity, because the food technologist has important opportunities to use these systems in a wide range of combinations with other potential inhibitors. Furthermore, it is arguable that although in vitro studies are necessary to investigate mechanisms of action and for intense genetical and biochemical studies, too few studies of natural systems have still been undertaken using actual foodstuffs. Sound and extensive food studies are essential rerequisites before food manufacturers will expend the effort or make the nvestment necessary to bring new preservation systems into successful expanded in recent years in response to consumers' requirements for fresher, more natural additive-free foods. With a few notable exceptions, very few of these systems have yet been taken through to application.

### Conclusions

niques available, there is also a surprisingly large and growing number This overview serves to highlight the fact that although there is a large and more-or-less traditional and stable range of food preservation techof improved technologies, and also radically new ones, that are being researched or are in the early stages of application.

and hopefully for consumers as well, so that their developing requirements This is heartening news for food technologists and for research workers, can continue to be effectively and safely satisfied in the future.

# 1 Principles and applications of hurdle technology L. LEISTNER

### .1 Introduction

The microbial stability and safety of most traditional and novel foods is based on a combination of several factors (hurdles), which should not be overcome by the microorganisms present. This is illustrated by the so-called hurdle effect. The hurdle effect is of fundamental importance for the preservation of foods, since the hurdles in a stable product control microbial spoilage, food-poisoning and, in some instances, the desired fermentation process [1, 2]. Leistner and co-workers acknowledged that the hurdle concept illustrates only the well-known fact that complex interactions of temperature, water activity, pH, redox potential, etc. are significant for the microbial stability of foods.

From an understanding of the hurdle effect, hurdle technology has been derived, which allows improvements in the safety and quality as well as the economic properties (i.e. how much water in a product is compatible with its stability) of foods, by an intelligent combination of hurdles [3-7]. Application of this concept (synonymously called combined methods, combined processes, combination preservation, combination techniques or Hürden-Technologie in German, Technologie des Barrières in French, Tecnologia degli Ostacoli in Italian, and hurdle technology in English) proved very successful, since an intelligent combination of hurdles secures the microbial stability and safety as well as the sensory, nutritive, and economic properties of a food.

# 1.2 Examples of the hurdle effect

For each stable and safe food a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product, however, in any case the hurdles must keep the 'normal' population of microorganisms in this food under control. The microorganisms present ('at the start') in a food product should not be able to overcome ('jump over') the hurdles present, otherwise the food will spoil or even cause food-poisoning.

The hurdle effect is illustrated in Figure 1.1, which gives eight examples. Example 1 represents a food which contains six hurdles, and these are:

Figure 1.1 Illustration of the hurdle effect, using eight examples. Symbols have the following meaning: F, heating, t, chilling; a, water activity; pH, acidification; E<sub>h</sub>, redox potential; pres.; preservatives; K-F, competitive flora; V, vitamins; N, nutrients. Figure taken from Leistner [1, 5].

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

which probably relates to a multi-target disturbance of the homeostasis of which are easily inhibited. On the other hand, as in example 4, if due to bad hygienic conditions too many undesirable microorganisms are initially present, even the usual hurdles inherent in a product may be unable to prevent spoilage or food-poisoning. Example 5 is a food rich in nutrients and vitamins, which will foster the growth of microorganisms (so-called 'trampoline effect'), and thus the hurdles in such a product must be enhanced, otherwise they will be overcome. Example 6 illustrates the bacterial spores in meat products are damaged sublethally by heat (as hurdles. In some foods the stability is achieved during processing by a sequence of hurdles, which are important in different stages of the ripening process and lead to a stable final product. Example 7 illustrates the high temperature during processing (F value), low temperature during occurs. A more likely situation is presented in example 2, since the redox potential. These five hurdles are sufficient to inhibit the usual types and numbers of microorganisms associated with such a product. If there are only a few microorganisms present at the start (example 3), then a few or low hurdles are sufficient for the stability of the product. The superclean or aseptic processing of perishable foods are based on this principle. The same proves true if the initial microbial load of a food (e.g. high moisture fruits) is substantially reduced (e.g. by blanching with steam), because after such a reduction only a few microorganisms are present at the start, occurs in F-SSP, discussed later), then the vegetative cells derived from such spores lack 'vitality', and therefore are inhibited by fewer or lower sequence of hurdles in fermented sausages, as will be discussed later. Finally, example 8 illustrates the possible synergistic effect of hurdles, storage (t value), water activity  $(a_w)$ , acidity (pH), redox potential  $(E_{
m h})$  of the product, as well as preservatives (pres.). The microorganisms present cannot overcome these hurdles, and thus the food is microbiologically nurdles are of the same height, i.e. have the same intensity, and this rarely whereas other less important hurdles are storage temperature, pH and behaviour of sublethally damaged organisms in food. If, for instance, stable and safe. However, example 1 is only a theoretical case, because all microbial stability of this product is based on hurdles of different intensity, In this particular product the main hurdles are a, and preservatives, microorganisms in foods (see section 1.3).

These examples of the hurdle effect have been given already some time ago [1, 5] but still are useful as an introduction to hurdle technology concept.

## 1.2.1 Fermented foods

In fermented foods - such as fermented sausages, raw hams and ripened cheeses - a sequence of hurdles leads to a stable and safe product. For

instance, in fermented sausages (salami) by the sequence of hurdles shown in Figure 1.1 (example 7) the food-poisoning and the spoilage organisms are inhibited, and the desired competitive flora (lactic acid bacteria) is selected. Important hurdles in the early stages of the ripening process of salami are nitrite and salt (pres.), which inhibit many of the bacteria in the batter. However, other bacteria are able to multiply, use up the oxygen and thus cause the redox potential of the product to decrease. This in turn enhances the E<sub>h</sub> hurdle, which inhibits aerobic organisms and favours the value, i.e. an increase of the pH hurdle. In long-ripened salami the nitrite increase again, i.e. all these hurdles become weak during a longer ripening of salami. Only the water activity hurdle (aw) is strengthened with time, and it is then mainly responsible for the stability of long-ripened raw The sequence of hurdles that secures the stability and safety of raw hams cheeses, a sequence of hurdles should be important for the proper ripening selection of lactic acid bacteria. They are the competitive flora (K-F) and sourish by metabolizing the added sugars, which causes a decrease in pH is depleted and the lactic acid bacteria vanish, while the En and pH sausage [4]. Since this sequence of hurdles has been revealed, the producis also known [9]. Probably also in other fermented foods, such as ripened tion of fermented sausages became less empiric and more advanced [8] process, and it would be challenging to elucidate them.

ripening process as well as the survival of pathogenic bacteria in the product. Therefore, the microstructure is an important hurdle for the i.e. the ripening flora only grow in nests (Figure 1.2). These nests are accumulated in such nests or cavities. Therefore, the ripening of salami is a 'solid-state-fermentation'. Within these nests the bacteria, either in pure the lactic acid bacteria prevail due to their tolerance of low En, pH, and aw. At the beginning of the sausage fermentation in these nests the of the ripening process the lactobacilli in their nests have degenerated and many have died. Small and equal distances between nests of desirable foster the necessary ripening process. The thorough mixing of the meat and fat particles of the sausage batter, before stuffing the sausage mix into casings, would bring about the desired more even distribution of bacteria in the sausage matrix. Moreov r, if starter cultures are used, they should Another feature peculiar to fermented sausages (and probably for ripened cheeses too) is their microstructure, which influences the desired stability of salami. Electron microscopy studies [10] have revealed that the natural flora as well as added cultures are not evenly distributed in fermented sausages, but are arrested in little cavities of the product,  $100-5000 \, \mu\mathrm{m}$  apart, and thus large areas of the sausage must be influenced by metabolites (e.g. nitrate reductase, catalase, lactic acid, bacteriocins) or mixed cultures, are in keen competition for nutrients and impair each other by their metabolic products. In nests of mixed cultures, generally lactobacilli appear vigorous and metabolically active, whereas at the end bacteria in the sausage matrix should be advantageous, since this would

PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY



Figure 1.2 Nest of bacteria in a fermented sausage (salami), surrounded by a firm sausage matrix. SEM, ×3600. From these nests desirable bacteria influence by metabolic products (e.g. organic acids, enzymes, bacteriocins) the ripening process of the entire food as well as nests of pathogenic bacteria (e.g. salmonellae or listeria) which are located in distant areas of the food matrix. Figure taken from Katsaras and Leistner [10].

be added in a fashion which favours an even distribution, and this could be achieved by using starter cultures not in a powdery but in a liquid state.

However, the microstructure is not only important for salami (and cheese), but for other foods too. In concentrate onli-in-water emulsions the bacterial growth is confined to the water droplets, which might lose their integrity due to coalescence [11]. The impact of microstructure on microbial growth, survival and death in foods has theoretical and practical implications. Certainly, under these circumstances predictive modelling of the behaviour of microorganisms is difficult. On the other hand, it is possible to influence the number, size, and distance of microbial nests in such foods, and thus their safety, stability and quality, by the recipes of the products and the technology applied.

# 1.2.2 Shelf stable products (SSP)

Heated high moisture foods based on hurdle technology, and thus storable without refrigeration, have been named shelf stable products (SSP), and they offer the following advantages: the mild heat treatment (70°-110°C)

German brühdauerwurst; guidelines for their processing have been suggested [4]. In the third type, the pH-SSP [3, 4], an increased acidity is the primary hurdle. This principle is applied in the Gelderse rookworst, a product which is storable without refrigeration and is exported from the Combi-SSP [5, 13], a combination of equal hurdles is applied, each of which adds a little weight on an imaginary balance [5], which should swing from the unstable to the stable state of the product. In an extensive study conducted for the German army, for military exercises, 75 meat products with fresh-product characteristics, but stable and safe without refrigeration for at least 6 days at 30°C, have been suggested [14], and they include of refrigeration simplifies distribution and saves energy during storage. SSP are heated in sealed containers (casings, pouches or cans), which avoid recontamination. However, because of the mild heat treatment these foods hurdles foster the safety and stability of these products too. In one type, unrefrigerated for several weeks, and have caused no problems with regard to food poisoning or spoilage, because guidelines for their processing have been suggested and followed [12]. The stability of another type, the aw-SSP [3, 4], is primarily caused by the reduction of the water activity below 0.95, and examples of traditional meats are Italian mortadella and Netherlands in large quantities to the UK. Finally, in the fourth type, the still contain viable spores of bacilli and clostridia, which are inhibited by an adjustment of a, pH, E, and, in the case of autoclaved sausages, by sublethal injury of the spores. At present four different types of SSP foods Examples are autoclaved sausages which have been prevalent in a considerable variety for about 10 years in German supermarkets. They are stored improves the sensory and nutritional properties of the food, and the lack are distinguished, depending on their primary hurdles, though additional the F-SSP [3, 4], the sublethal damage of the spores is the primary hurdle. F-SSP, aw-SSP, pH-SSP, and Combi-SSP [13]

However, not only meat products but other foods too could be stabilized as SSP. For instance, an Italian pasta product (tortellini) was stabilized by using as hurdles a water activity reduction and mild heat processing, as with moderate chilling temperatures [15, 16]. Another example is paneer 17, 18], a dairy product of India, which was developed as Combi-SSP, and will be discussed later. In both cases the thesis work of young scientists well as modified atmosphere or ethanol vapour during storage, combined was breaking the ground.

# 1.2.3 Intermediate moisture foods (IMF)

Intermediate moisture foods (IMF) are in the  $a_{\overline{w}}$ -range of 0.90-0.60, and pH, and  $E_h$  [19]. These foods are easy to prepare and storable without refrigeration, i.e. they are cost and energy efficient. Traditional IMF based are often stabilized by additional hurdles, such as heating, preservatives,

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

on meat, fish, fruits and vegetables are common and much liked in different parts of the world, because they are tasty, nutritious, and in general safe. However, the novel IMF have not achieved the expected breakthrough in human nutrition. Some reasons for this disappointing performance are the poor palatability of novel IMF due to the high concentration of humectants, and the need to introduce often high amounts of antimicrobial additives ('chemical overloading of foods') which may cause health concerns and pose legal problems.

Chinese dried meats, South African biltong, and Turkish pastirma, have and safety of some traditional IMF meat products, i.e. Chinese sausage, been described in detail and guidelines for their manufacturing were given [4]. These published facts will not be repeated here. The stability and Fin previous communications [2-4] the properties, processing, stability, safety of such traditional meats, which are all in the intermediate moisture range, is based on empiric application of hurdle technology [20]

Sosta Rica, Cuba, Chile, Mexico, Nicaragua, Puerto Rico, Uruguay, and Venezuela) on traditional foods of the region, which are storable without refrigeration. In the course of this study (CYTED-D AHI), which was sponsored by Spain, about 260 food items, representing fruits and vegestables, and foods derived from fish, milk, meat, cereals, as well as mishigh moisture foods was based on empirically applied combined methods Other examples of empiric applied hurdle technology revealed an extensive study done in 10 Latin America countries (Argentina, Brazil, cellaneous products were identified, which are stable and safe without efrigeration [21-23]. The majority of these food items were IMF, however some vegetable, meat, fish, cheese, and bakery products had a higher a,, sometimes as high as 0.97-0.98. It turned out that the stability of these (CM technology'), i.e. hurdle technology. The understanding of this fact has opened a new avenue of food preservation in Latin America, which is now applied especially to tropical and subtropical fruits in small and bulk containers, as will be discussed later (see section 1.5.1). In the opinion of Latin American scientists [22, 23] the technological achievements of Ibero-America in this area deserve a closer look, in particular by developing countries where refrigeration is scarce. The Latin American approach, that as first to obtain an inventory on foods available in the region which have and need for refrigeration, secondly to reveal the underlying principles behind their stability and finally to improve the stability and quality of such foods by application of hurdle technology, is now pursued in India [18] and China [24, 25]. Since IMF are often not satisfactory from the sensory point and contain high levels of additives, the application of CM technology (hurdle technology) to stabilize high moisture foods, which also need no refrigeration, seems to have great potential [23]

# 1.3 Behaviour of microorganisms during food preservation

environment determines whether they may grow or die. Related to these responses more basic research and its application are needed, because this might lead to new dimensions of food preservation. At present there are ment, in order to inhibit their growth or shorten their survival or cause their death. The feasible responses of microorganisms to such a hostile more questions than answers available, as the following discussion will Food preservation implies putting microorganisms in a hostile environ-

# 1.3.1 Homeostasis of microorganisms

before their homeostasis is re-established ('repaired'). Thus, food preservation is achieved by disturbing the homeostasis of the microorganisms in of living organisms [27], and this applies to higher organisms as well as to microorganisms. Much is already known about the homeostasis in higher organisms at the molecular, subcellular, cellular and systematic levels in This knowledge should now be transferred to microorganisms important their internal equilibrium, is disturbed by preservative factors (hurdles) in is the interference by the food with the homeostasis of microorganisms nance of a defined pH within narrow limits is a prerequisite and feature foods, they will not multiply, i.e. remain in the lag-phase or even die, An important phenomenon, which deserves attention in food preservation [26]. Homeostasis is the tendency to uniformity or stability in the normal status (internal environment) of the organisms. For instance, the maintethe field of molecular biology, biochemistry, physiology and medicine [27]. for the preservation of foods. If the homeostasis of microorganisms, i.e. a food temporarily or permanently.

osmoregulation of microorganisms has been studied already extensively with respect to food preservation. Considerable knowledge is available role of potassium as well as the accumulation of amino acids or polyols (as compatible solutes), in order to reverse plasmolysis and re-establish a ment with low a... Gould and co-workers pointed out that cell osmoregulation mechanisms involve a considerable energy cost for the synthesis or accumulation of 'compatible solutes'. Thus, any restriction of energy supply will tend to be especially synergistic with lowered a, when used as method of food preservation [30]. The principles of other known 'repair mechanisms' of the microbial cells under stress should be applied to food Since food stability is often achieved by water activity reduction, the about the osmoregulatory mechanisms of microorganisms [28-32], and the metabolically suitable water content inside the cells living in an environpreservation too, i.e. could be related to hurdle technology.

## PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY 3.2 Multi-target preservation of foods

Rar foods preserved by hurdle technology, it has been suspected for some time that different hurdles in a food could not just have an additive effect lustrates this. A synergistic effect could become true if the hurdles in a nzyme systems, pH, a, E, within the microbial cell, and thus disturb he homeostasis of the microorganisms present in several respects. Therepresemploying different hurdles in the preservation of a particular food on stability, but may act synergistically [1]. Example 8 in Figure 1.1 bod hit, at the same time, different targets (e.g. cell membrane, DNA, fould have advantages, because microbial stability could be achieved with a intelligent combination of gentle hurdles.

we in larger amounts, because different preservatives might hit different argets within the bacterial cell, and thus act synergistically [6, 7]. This multi-target preservation' of foods could become a promising research int most effective preservation of foods could be accomplished. It is nticipated that the targets in microorganisms of the different preservative actors (or hurdles) for foods will be elucidated, and then the hurdles could grouped into target-classes. A mild and effective preservation of foods, e a synergistic effect of hurdles, is likely if the preservation measures are ased on an intelligent selection and composition of multi-target hurdles In practical terms, this could mean that it is more effective to use ifferent preservatives in small amounts in a food than only one preservagea, because if small hurdles with different targets are selected, a minimal ken from different target-classes.

# 3.3 Stress reactions and metabolic exhaustion

me bacteria become more resistant (e.g. toward heat) under stress low pH or catalase inactivation in heat-injured cells). These responses light influence the preservation of foods, because increased resistance nder stress could turn out to be problematic in the application of hurdle ome primarily from the inhibition of growth, and are less related to urvival and death of microorganisms. Nevertheless, further research in echanisms which could switch them on, seems warranted in relation to dianol, etc.), or they are less heat-resistant under stress (and this induced echnology [33]. However, benefits of the application of hurdle technology ress proteins, the time factor for their synthesis, and the different ecause the synthesis of protective stress proteins is induced by heat, a,, de application of hurdle technology for food preservation.

erilization of stable hurdle technology foods during storage. This was st observed by us and initially not believed, many years ago [34], with ilidly heated (95°C core temperature) liver sausage adjusted to different Another phenomenon of certainly practical importance is the 'auto-

stable SSP actually decrease during storage at ambient temperatures. Also ated storage, especially on meats with a water activity close to the threshold for microbial growth. Again the same phenomenon was observed by Latin American researchers [36, 49] in their studies with high explanation for this behaviour might be that vegetative microorganisms which cannot grow will die, and they die more quickly if the stability is Apparently, the microorganisms in stable hurdles technology foods strain metabolically exhausted. Thus, due to autosterilization, the hurdle technology foods, which are microbiologically stable, become more safe during storage, especially at ambient temperatures. So, for example, salmonellae which survived the ripening process in fermented sausages, will vanish Clostridial spores which survived the heat treatment vanished in the The most likely explanation is that bacterial spores which survive the heat treatment are able to germinate in these foods under conditions that are less favourable than those under which vegetative cells of bacilli and clostridia are able to multiply [5]. Therefore, during storage of these vegetative cells deriving from these spores die. Thus the spore counts in during studies in our laboratory, with Chinese dried meat products, we observed the same behaviour [35]. If these meats were recontaminated after processing with staphylococci, salmonellae or yeasts, the counts of these microorganisms on stable products decreased fast during unrefrigermoisture fruit products (HMFP), because the counts of a variety of bacteria, yeasts, and moulds which survived the mild heat treatment, decrease quite fast in the products during unrefrigerated storage, because the hurdles applied (see section 1.5.1) did not allow growth. A general close to the threshold for growth, storage temperature is elevated, antievery possible repair mechanism to overcome the hostile environment, by doing this they completely use up their energy and die, if they become more quickly if the products are stored at ambient temperatures, and they water activities by the addition of salt and fat, and the product was product during storage, if the products were stable. Later this behaviour of clostridia as well as Bacillus spores was regularly observed during products some viable spores germinate, but the germinated spores or microbial substances are present, and the organisms are heat-injured. inoculated with Clostridium sporogenes PA 3679 and stored at 37°C. storage of SSP meat products (see section 1.2.2), especially with F-SSP will survive longer in products stored under refrigeration.

## 1.4 Total quality of foods

Stanley [37] indicated that the hurdle technology approach seems to be applicable to a wider concept of food preservation than just microbial

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

but that, in order for it to work, a precise knowledge of the teness of each hurdle for a given commodity is required. Furtherthe suggested distinguishing between positive and negative hurdles enna [38] emphasized that while hurdle technology is appropriate for the microbial stability and safety of foods, the total quality of sat aspects of microbial stability and safety. But at present the tools quality of foods [37]. Certainly, hurdle technology is not only ical and chemical attributes. The concept of combined processes dwork towards the total quality of foods rather than the narrow but is it equally true for predicting food quality by modelling. As an step towards improving total food quality, the HACCP (Hazard stot HACCP have been already well established, however, in the mical and physical hazards [39], whereas the application of the HACCP ible to safety, but also to quality aspects of foods [7]. However, phying hurdle technology to total food quality are still not adequate, sisr Critical Control Points) procedure should be converted from sses for as many quality enhancements as is possible [38]. The pringrammuch broader field and encompasses a wide range of physical, fargets to other quality targets. The applicati n of combined procesillosophy to physical product quality should be a future development. archers should appreciate the wider power of the hurdle technology ptrand food industry should use the available tools of combined sense HACCP had to be used exclusively to avoid biological, ept for quality aspects of foods seems sensible it is still disputed

## Optimal range of hurdles

me-time improve the flavour of the product; and this also applies to whe negative or positive for securing the desired total quality of a nalarange [6]. If the intensity of a particular hurdle in a food is too sit should be strengthened; on the other hand, if it is detrimental to food quality it should be lowered. By this adjustment, the hurdles in inveles ( ) will and rearried from influence the safety as well equality of foods, because they have antimicrobial properties and at sused in the curing of meat. The possible hurdles in foods might mee the stability and safety, as well as the sensory, nutritive, techscal, and economic properties of a product, and the hurdles present Moreover, the same hurdle could have a positive or a negative effect ods, depending on its intensity. For instance, chilling to an unsuitable inted sausages, which should be low enough to inhibit pathogenic ana, but not so low as to impair taste. In order to secure the total of a food, the safety and quality hurdles should be kept in the eas moderate chilling is beneficial. Another example is the pH of emperature will be detrimental to fruit quality ('chilling injury')

foods should be kept in the optimal range, considering safety as well as quality [7]

## 1.4.2 Potential safety and quality hurdles

respiring produce, edible coatings, ethanol vapour, Maillard reaction products, and bacteriocins). Although about 50 hurdles have been already preservatives (e.g. nitrite, sorbate, sulfite). However, in addition, more modified atmosphere packaging for non-respiring products as well as identified, the list of possible hurdles for the preservation of foods is by tial  $(E_{\rm h})$ , competitive microorganisms (e.g. lactic acid bacteria), and than 50 hurdles of potential use for foods of animal or plant origin, which improve the stability and/or the quality of these products, have hitherto been identified (Table 1.1). In the Final Report of a FLAIR Concerted Action No. 7, Subgroup B [40], these hurdles have been described by Bøgh-Sørensen [41], and other members of the group have briefly reviewed in this Report some of the emerging hurdles (ultrahigh pressure, no means closed. But not all of these hurdles will be commonly applied, The most important hurdles commonly used in food preservation, either applied as 'process' or 'additive' hurdles, are high temperature (F value), low temperature (t value), water activity  $(a_w)$ , acidity (pH), redox potenmano-thermo-sonication, photodynamic inactivation of microorganisms, and certainly not all of them for the same food product.

## 1.4.3 User guide to food design

stable, safe and high quality foods should now be accomplished. This strategy could be applied in an effective food design, for which a user guide Hurdle technology as a concept has proved useful in the optimization of However, it should be combined, if possible, with the HACCP concept and predictive microbiology. These three concepts are related. However, hurdle technology is primarily used for food design, the HACCP concept By considering these different approaches, an overall strategy for securing raditional foods as well as in the development of novel products. for process control, and predictive microbiology for process refinement. was tentatively suggested [42].

must be standardized and reproducible. Therefore, for the first time, a if produced by large or small enterprises, the manufacturing processes refrigeration [14]. Eight categories of meat products were selected and optimized. Since these meats should be suitable for army provisions, even product characteristics which nevertheless are storable without The Federal Centre for Meat Research, Kulmbach, demonstrated the efficiency of hurdle technology for food preservation in a study (supported by the Medical Corps of the German Army) on meat products with fresh-

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

fibilist. Incomplete list of potential hurdles for foods of animal or plant origin, which fippove the stability and/or quality of these products [6, 41]

imperature (low or high) He(low or high)

(low or high)

dified atmosphere (carbon dioxide, oxygen, nitrogen, etc.)

ikkaging (vacuum packaging, active packaging, aseptic packaging, new edible coatings, etc.)

essure (high or low)

feliation (microwaves, UV, lonizing, irradiation, etc.)
ther physical processes (ohmic heating, high electric field pulses, radiofrequency energy, stillating magnetic fields, photodynamic inactivation, ultrasonication, etc.) icrostructure (emulsions, solid-state-fermentation, etc.)

inpetitive flora (lactic acid bacteria, etc.)

is monolaurin, chelators, Maillard reaction products, ethanol, spices, nitrite, nitrate, fife, smoke, ozone, hypochlorite, pimaricin, lysozyme, lactoperoxidase, nisin, other elta-lactone, polyphosphates, propylene glycol, diphenyl, chitosan, free fatty acids, pheservatives (organic acids, lactate, acetate, sorbate, ascorbate, isoascorbates, gluconocteriocins, etc.)

groduced [14, 43]. In the manufacturing plants processing the recomfixinge between hurdle technology and the HACCP concept was nded meats, no microbiological tests have to be carried out; however, pe, temperature, pH, and a... These measurements should be done fline, or at least close to the line. A new instrument became available §45], which allows aw determinations of meat products within 10-20 nutes. The mentioned army study could be used as a model for other her process parameters have to be strictly controlled, and these are: fances, where hurdle technology and HACCP should be linked [13].

The army project also raised the question of how food design should be promising concept which allows computer-based and quantitative dictions of microbial growth, survival and death in foods. However, the EpH, a, (due to salt or humectants), preservatives (e.g. nitrite, lactic by, and quality of particular foods. It is unlikely that all, or even a jority of these hurdles, could be covered by predictive modelling. Thus edictive microbiology cannot be a quantitative approach to the totality state of microorganisms in food systems, while considering few but the st important factors (hurdles). Because several hurdles are not taken dictive models constructed so far handle only up to four different fors (hurdles) simultaneously. Factors considered to date are temperaand CO<sub>2</sub>. As outlined in section 1.4.2, there are numerous other hurdle technology. However, it does allow quite reliable predictions of o account, the predicted results are fortunately often on the safe side, possibly predictive microbiology too. Predictive microbiology [46-48] eyant hurdles to be considered, which are important for the stability, ie in general, by applying hurdle technology combined with HACCP

reduce both time and costs spent in product development. Thus predictive i.e. the limits indicated for growth of pathogens in foods by the models available are in general more prudent ('fail-safe') than the limits in real foods [6, 7]. But predictive microbiology will be an important tool in future food design, because it can narrow down considerably the range over Although it will never render challenge testing obsolete, it may greatly which challenge tests with relevant microorganisms need to be performed microbiology should be an integral part of advanced food design [7].

proved appropriate when solving real product development tasks in the food industry. These steps are listed in Table 1.2, but still should be For the design of foods 10 steps have been suggested [13, 42] which considered as tentative, until further practical experiences with the application of this user guide have accumulated in the food industry.

by taking the legal, technological, sensory, and nutritive limitations into biologists, must work together. The technologist should determine which processes or additives are proper for the enhancement of hurdles in a food, In food design different disciplines, including technologists and microTable 1.2 Steps for food design using an integrated concept, comprising hurdle technology as well as predictive microbiology and HACCP [42]

- First, for the modified or novel food product the desired sensory properties and the desired shelf-life must be defined.
- Secondly, a tenative technology for the production of the food should be suggested.
- The food is now manufactured according to this technology, and the resulting product is analysed for pH,  $a_{w}$ , preservatives or other inhibitory factors, and the temperatures for heating (if intended) and storage as well as the expected shelf-life are defined.
- For preliminary stability testing of the suggested food product, predictive microbiology could be employed.
- The product is now challenged with food-poisoning and spoilage microorganisms, using somewhat higher inocula and storage temperatures than 'normal'.
- If necessary, the hurdles in the product are modified, taking the homeostasis of the microorganisms and the sensory quality of the food (i.e. 'total quality') into considera-
- The modified product is again challenged with relevant microorganisms, and if necessary the hurdles are modified once more. Predictive microbiology for assessing the safety of the food might be helpful at this stage too.
- Now that the established hurdles of the modified or novel food are exactly defined, including tolerances, the methods for monitoring the process are defined (preferably physical methods should be used).
- 9. Thereafter, the designed food should be produced under industrial conditions, because the possibilities for a scale-up of the proposed process must be validated.
- 10. Finally, for the industrial process the critical control points (CCPs) and their monitoring has to be established, and thus the manufacturing process should be controlled by HACCP

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

htrdles in a particular food are needed for the desired safety and bility of the product. Because the engineering, economic, and marketdaspects have to be taken into consideration too, food design is indeed unt. The microbiologist should determine which types and intensity miltidisciplinary endeavour.

# Application of hurdle technology in less devel ped countries

mitoring devices the intentional use increases. Recent examples of an whigent application of hurdle technology in developing countries are the ds based on hurdle technology are prevalent in industrialized as well in developing countries. In the past and often still today hurdle techgnow with a better understanding of these principles and improved Servation of various fruits in Latin America, a dairy product in India, smeat products in China. Therefore, these developments will be briefly ggy was applied empirically without knowing the governing principles. gassed here.

geusly available. Furthermore, in less developed countries food For developing countries, foods storable without refrigeration are of cial interest, because refrigeration (energy) is costly and not conich fulfil these requirements, has been accumulated in different parts of sworld. Most of the foods which remain stable, safe and tasty during Servation procedures should be inexpensive and simple, but reliable. storage without refrigeration, even under the difficult climatic ditions prevalent in many developing countries, are intermediate moiswever, such foods are often not sufficiently palatable (too sweet or sture foods (with a water activity as high as 0.95-0.98), which are actoo. In order to illustrate which improvements in traditional foods already been achieved in different developing countries by using eenturies a treasure of knowledge of food preservation methods, efoods (see section 1.2.3), with an awrange from 0.90 to 0.60. and/or too tough). Therefore, research is now directed toward high bilized by additional hurdles and thus can be stored without refrigeradle technology for high moisture foods, the following examples will be ented.

## Fruits of Latin America

Sture fruit products (HMFP: a, high r than 0.92) in seven Latin cently, processes have been developed for the preservation of high itto Rico, and Venezuela), and have been applied to peach halves, erican countries (Argentina, Costa Rica, Cuba, Mexico, Nicaragua, eapple slices, mango slices and purée, papaya slices, chicozapote slices,

syrup of the products. Thus, 'combined methods technology' (hurdle technology) was applied in these novel processes [36, 49, 50-52]. Hurdle ppm for the syrup; during storage of HMFP the sorbate and in particular strawberries, and pomalaca [49, 50]. The new technologies were based on the combination of a mild heat treatment (blanching for 1-2 min with saturated steam), slight reduction in water activity (to 0.98-0.93, by the addition of glucose or sucrose), lowering of pH (to 4.1-3.0, by the addition of citric or phosphoric acids) and the addition of antimicrobials (potassium sorbate or sodium benzoate, and sodium sulfite or sodium bisulfite) to the combinations often used for HMFP have been:  $a_{\rm w} = 0.97$ , pH = 3.5, and the addition of potassium sorbate = 1000 ppm and sodium bisulfite = 150 the sulfite levels decreased, whereas the a, fell (the a,-hurdle increased) purée of banana, plum, passion fruit, and tamarind, as well as whole figs, due to the hydrolysis of sucrose [50, 51].

subtropical fruits, many of them having exotic and quite distinctive bined methods applied allow storage of fruits, without losses between The resulting fresh-like products were still scored highly by 30-50 member colour, and especially for texture, which is often problematic for canned fruits. Thus, according to Latin American researchers [49-51], the comseasonal harvest peaks, for direct domestic consumption and for further processing to confectionery, bakery and dairy products, or for preserves, HMFP will open new possibilities for export markets. In general, they provide a better utilization of Latin American indigenous tropical and These minimal processes proved energy efficient, simple to carry out (little capital investment), and were satisfactory to preserve fruits in situ. consumer panels after 3 months of storage at 35°C for taste, flavour, barbecues, pizzas and fruit drink formulations. Moreover, these novel ams, and jellies. Fruit pieces can also be utilized as ingredients in salads, flavours, textures and appearances.

biological results obtained with HMFP are probably due to 'metabolic bacilli, known to spoil fruits, and stored without refrigeration for 120 days and often vanished below the detection limit. These favourable microexhaustion' of the microorganisms present in the stabilized products (see The high moisture fruit products stabilized by hurdle technology proved yeasts and moulds further decreased, often to below the detection limits 36, 49-52]. Banana purée challenged with yeasts, moulds, clostridia and adjustment of  $a_w = 0.97$  and pH = 3.4, addition of 100 ppm ascorbic acid and 400 ppm sodium bisulfite). The inoculated microorganisms declined shelf-stable during 3-8 months storage at 25-35°C. Due to the blanching process the initial microbial counts were substantially reduced, and during the storage of the stabilized HMFP the number of surviving bacteria, remained stable if proper hurdles were applied (mild heat treatment, section 1.3.3)

Alzamora and co-workers expressed the opinion that HMFP-

this novel process by the food industry [50]. However, the preservation eduse they are easy to implement and will improve considerably the fality of stored fruits [49]. They even believe that the usefulness of birdbined methods (hurdle technology) for HMFP may give rise to an splosion' of research on minimally processed fruits, and the application HMFP must certainly be based on guidelines for good manufacturing actice (GMP) or preferably on hazard analysis critical control points ACCP), in order to be successful under artisan or industrial conditions gersection 1.4.3). For instance, the reuse of syrup may become a risk in defion to a build-up of the spoilage flora (e.g. Zygosaccharomyces bailii, fifeth could be sorbate-resistant), and therefore the reuse of syrup in fatiologies will attract much attention in many developing countries, WIFF processes should only be recommended after pasteurization.

## Dairy product of India

seer is a traditional, cottage-cheese type product in fried cubes, with mate sauce, onions, and spices, which is frequently consumed and much dwever, paneer generally spoils at room temperature (which in India can er be 35°C) within 2 days, and this is an immense drawback for its Well in India, because of its nutritive value and characteristic taste. fastrial production.

in India, Dr K. Jayaraj Rao, in the German Federal Centre for Meat Sterilized paneer in cans has severe sensory limitations with regard to vour; texture and colour. Therefore, together with a visiting scientist search, Kulmbach, a mildly heated paneer in cans, with the desired wour (like prepared fresh), colour (little browning) and texture (not too idisthus is stable and safe for several weeks without refrigeration. The idd) was developed. This product was stabilized by hurdle technology, sawing combinations of hurdles proved effective with this product:  $\Rightarrow 0.97$ , heating to F value of 0.8, pH = 5.0 or alternatively  $a_w = 0.96$ , = 0.4, pH = 5.0[17].

murdle technology to fried paneer in cubes made from buffalo milk. The after his return to India, K.J. Rao continued his work with application maset of hurdles, i.e. F = 0.8,  $a_w = 0.95$ , pH = 5.0, and 0.1% potassium thate; was chosen, which had maximum lethal and inhibitory effect on fracteristics [18]. The water activity of paneer and gravy was lowered by Sing humectants, such as dahi, skim milk powder, salt and glycerol. The Hawas adjusted by changing the dahi: skim milk powder ratio. The stilling product had a keeping quality of 1 month at 30°C or over 3 ouths at 15°C. The product was compared with fresh samples from staurants and was found to be equally acceptable. In the opinion of educt with gravy was packed either in tins or flexible retort pouches, ersorganisms and minimum effects on textural and chemical

Rao [18], this method of preservation has a large scope for alterations in product formulations, depending on regional taste preferences, without affecting the keeping quality of the product.

Via paneer the hurdle technology was introduced into food science of India, and its application to a variety of indigenous foods is anticipated.

## 1.5.3 Meat products of China

in total uses more meat than any other country in the world, are processed into meat products, and dried meats are very popular. There are three technologies in use for Chinese dried meat production [4], but one variety (rou gan) constitutes more than 95% of the dried meats of China [24]. The technology used for the production of rou gan has not changed for About 15% of the meat supply of the Peoples Republic of China, which hundreds of years, but improvements are possible and desirable.

lighter colour and less sweet taste, i.e. lower sugar addition. Shafu is an improved rou gan which fulfils these expectations, and therefore has been well accepted in the Chinese market. Whereas traditional rou gan has a sensory pr perties, has an aw of about 0.79, and nevertheless is storable without refrigeration [24]. Compared with rou gan the moisture content of shafu is higher, and salt and sugar contents are lower. Whereas nitrate is added to rou gan, shafu is produced with nitrite curing salt, and the finished product is vacuum packaged. Both products have low residual levels of nitrite and nitrate, contain few microorganisms including in The Chinese consumer now prefers products with a softer texture, water activity below 0.70, the novel product shafu, with much superior general no pathogenic or toxigenic bacteria, and may be stored for several months without refrigeration.

rou gan, are due to an intelligent application of hurdle technology, and it may be expected that similar modification in the future will be used for The superior sensory properties of shafu, compared with the traditional other Chinese meats [24].

use of hurdle technology the sensory properties of these meats might be optimized, without sacrificing their microbial stability and safety. For other produced by empirically applied hurdle technology. Now, with a deliberate Traditional meat products of China are quite simple to produce, have a refrigeration. An inventory of the processing and the properties of traditional Chinese meats has been established [25], which covers Chinese pork floss (rou song), Chinese sausage (la chang), and Chinese raw ham (yu nam ho tui and chin hua ho tui). As a second step, the principles of characteristic taste, and they are storable for an extended time without bacon (la rou), pressed duck (ban ya), silk rabbit (chan si tu), cured chicken (yuan bao ji), dried meat (rou gan), sweet dried meat (rou pu), the stability and quality of these meats were described, which are all

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

bild be of interest, as well as for industrialized countries as a source of sloping countries, where the storage of meat products without refrigerdries desirable too, the traditional and improved Chinese technologies

### Future potential

stability and quality of most foods is based on empirical and more antly on knowingly employed hurdle technology. To follow this successfoute, further basic as well as applied research is needed.

he basic research in this context should centre around the interrelation anisms, and finally to a materialization of the multi-target preservation homeostasis and hurdle technology. Results could lead to a better ferstanding of stress reactions and the metabolic exhaustion of microoods, as a new concept.

Sonic radiation, should be strengthened, because it might well turn Mand intermediate moisture foods (IMF), many more applications fore on the applied side is the exploration and further applications of diestechnology in order to improve quality and stability, i.e. total lity of foods. The validation of the suggested user guide to food design, th should include predictive microbiology as well as HACCP, seems Eurthermore, the coupling of hurdle technology with modern servation methods for foods, such as irradiation, ultrahigh pressure or that it is essential for these processes too. Related to more traditional ervation methods, such as fermented foods, shelf-stable products urdle technology probably are in store than have been explored urdle technology has advantages for chilled foods too, e.g. as a backgeasure ('invisible technology') in the case of temperature abuse in display or in the home of the consumer. However, the most impresstrides in the application of hurdle technology have been made with s which remain stable, safe and tasty even if stored without refrigera-A case in point is the admirable achievements of Latin America in ect of the stabilization and quality improvement of a variety of mally processed high moisture fruits, which are storable without might lead to impressive results there too. It may be expected that dle technology foods with a relatively high water activity will partially lace intermediate moisture foods, because lower amounts of humecsand less drying are required, and this would be desirable from the asory and nutritive point of view. However, deliberate hurdle technolshould be applied without sacrificing the microbial stability and safety geration. Similar ideas have caught on in China as well as in India, Gods, especially those which are stored without refrigeration. There-

they will require a thorough understanding of the principles involved as well as more back-up by good manufacturing practice (GMP) and possibly fore, if the hurdle technology foods are to become more sophisticated, by the HACCP concept.

### References

- Leistner, L. (1978) In Food Quality and Nutrition, ed Downey, W.K. Applied Science
- Publishers, London, p. 553.

  2. Leistner, L., Rodel, W. and Krispien, K. (1981) In Water Activity: Influences on Food Quality, eds Rockland, L.B. and Stewart, G.F. Academic Press, New York, p. 855.
  - Leistner, L. (1985) In Properties of Water in Foods in Relation to Quality and Stability, eds Simatos, D. and Multon, J.L. Martinus Nijhoff Publishers, Dordrecht, p. 309.
    - 4. Leistner, L. (1987) In Water Activity: Theory and Applications to Food, eds Rockland, L.B. and Beuchat, L.R. Marcel Dekker, New York, p. 295. Leistner, L. (1992) Food Res. Internat., 25, 151.
- Leistner, L. (1994) J. Food Engineer., 22, 4211.
  Leistner, L. (1994) In Food Preservation by Combined Processes, eds Leistner, L. and Gorris, L.G.M. Final Report of FLAIR Concerted Action No. 7, Sub-group B, EUR 15776 EN p.1.
- Leistner, L. (1992) In New Technologies for Meat and Meat Products, eds Smulders, F.J.M., Toldrá, F., Flores, J. and Prieto, M. (1992) Audet Tijdschriften p.1.
- 9. Leistner, L. (1986) Fletschwirzschaft, 66, 496. 10. Katsaras, K. and Leistner, L. (1991) Biofouling, 5, 115. 11. Robins, M., Brocklehurst, T. and Wilson, P. (1994) Food Technology International Europe (in press).
- 12. Hechelmann, H. and Leistner, L. (1984) Mitteilungsblatt Bundesanst. Fleischforsch. Kulmbach, 84, 5894
  - Leistner, L. and Hechelmann, H. (1994) In Proc. Food Pres. 2000 Conf., US Army Research, Natick (in press). 13
    - Hechelmann, H., Kasprowiak, R., Reil, S., Bergmann, A. and Leismer, L. (1991) Stabile Fleischerzeugnisse mit Frischprodukt-Charakter für die Truppe, Bundesminster der Verteidigung, FBWM 91-11, Bonn. 14.
      - Giavedoni. P. (1994) Azioni combinante nella stabilizzazione degli alimenti, PhD Thesis Udine, Italy 13
- 16. Giavedoni, P., Rôdel, W. and Dresel, J. (1994) Fleischwirzchaft, 74, 639. Kulmbach, 31, 293
- Rao, K.J. (1993) Application of Hurdle Technology in the Development of Long Life Paneer-Based Convenience Food. PhD Thesis, Kamal, India. Leistner, L. and Rödel, W. (1976) in Intermediate Moisture Foods, eds Davies, R., Birch, G.G. and Parker, K.J. Applied Science Publishers, London, p. 120. Leistner, L. (1990) in Proc. 26th Int. Congr. Meat Sci. Technol., Vol. III, Havana, p. 842.
- Aguilera Radic, J.M., Chirife, J., Tapia de Daza, M.S., Welti Chanes, J. and Parada Arias, E. (1990) Inventario de alimentos de humedad intermedia tradicionales de Iberoamerica, Instituto Politecnico Nacional, Mexico. 7

ध्रं

- Aguilera, J.M., Chirife, J., Parada Arias, E. and Barbosa Canovas, G.V. (1993) In Food Dehydration, eds Barbosa Cánovas, G.V. and Okos, M.R. American Institute of Chemical Engineers, New York, p. 72. Welti, J., Tapia de Daza, M.S., Aguilera, J.M., Chrife, J., Parada, E., Lopez Mals, A., Lopez, L. C. and Corte, P. (1994) Revista Espanola de Ciencia y Tecnología de Alimentos ង
- 422
- Wang, W. and Leistner, L. (1993) Fleischwirtschaft, 73, 854.
  Wang, W. and Leistner, L. (1994) Fleischwirtschaft, 74 (in press).
  Gould, G.W. (1988) In Homeostatic Mechanisms in Micro-organisms, eds Whittenbury, R., Gould, G.W., Banks, J.G. and Board, R.G. Bath University Press, Bath, p. 220.

# PRINCIPLES AND APPLICATIONS OF HURDLE TECHNOLOGY

Bussinger, D. (ed.) (1988) pH Homeostatis - Mechanisms and Control, Academic

ristian, J.H.B. (1955) Aust. J. Biol. Sci., 8, 490.

ids Simatos D. and Multon, J.L. Martinus Nijhoff Publishers, Dordrecht, p. 229.

Soller, J.A. (1987) In Water Activity: Theory and Applications to Food, eds Rockland Brown, A.D. (1978) Adv. Microb. Physiol., 17, 181.

Giald, G.W., Brown, M.H. and Fletcher, B.C. (1983) In Food Microbiology: Advances and Prospects, eds Roberts T.A. and Skinner, F.A. Academic Fress, London, p. 67.

Gould, G.W. (1985) In Properties of Water in Foods in Relation to Quality and Stability,

avier, I.J., Ugborogho, T.O. and Ingham, S.C. (1994) In Proc. Food Pres. 2000 B. and Beuchat, L.R. Marcel Dekker, New York, p. 101.

istner, L. and Karan-Djurdjie, S. (1970) Fletschwirtschaft, S0, 1547. onfer., US Army Research, Natick (in press)

iin, H.K. (1984) Energiesparende Konservierungsmethoden für Fleischerzeugnisse, geleitet von traditionellen Intermediate Moisture Foods. PhD Thesis, Stuttgarthenheim, Germany.

INES. (1985) Preconservación de duraznos por métodos combinados. MS Thesis, Mar

ney, D.W. (1991) Crt. Rev. Fd. Sci, Nut., 30, 487. Kenna, B.M. (1994) In Food Preservation by Combined Processes, eds Leistner, L. Contis, L.G.M. Final Report of FLAIR Concerted Action No. 7, Subgroup B, EUR

ison, M.D. and Corlett, D. jr. (1992) HACCP: Principles and Applications, Van Madyd Reinhold, a Division of Wadsworth, USA.

Sipper, L. and Gorris, L.O.M. eds (1994) Food Preservation by Combined Processes, Report of FLAIR Concerted Action No. 7, Subgroup B, EUR 15776 EN.

and Gorns, L.G.M. Final Report of FLAIR Concerted Action No. 7, Subgroup B, (1994) In Food Preservation by Combined Processes, eds Leistner UR 15776 EN, p. 7 -Sørensen, L.

istict. L. (1994) In Food Preservation by Combined Processes, eds Leistner, L. and 76 EN, p. 25.

stuer, L. (1993) In Proc. 45th Ann. Reciprocal Meat Conf., p. 1. (1993) In Proc. 45th Ann. Reciprocal Meat Conf., p. 1. (1994) W., Scheuer, R. and Wagner, H. (1990) Fleischwirzschaft, 70, 905. (1989) Food Science and Technology Today, 3, 89. (1989) Rosanyi, J., Boogard, E., Kelly, T.M. and Roberts, T.A. (1993) Int. J.

deekin, T.A., Olley, J.N., Ross, T. and Ratkowsky, D.A. (1993) Predictive Microgamora, S.M., Tapia, M.S., Argaiz, A. and Welti, J. (1993) Food Res. Internat., 26, 108y: Theory and Application, Research Studies Press, Taunto

澄如ora, S.M., Cerrutti, P., Guerrero, S. and Lopez Malo, A. (1994) In Proc. 80POW - Practicum II, Puebla (in press)

Spez Malo, A., Palou, E., Welti, J., Corte, P. and Argaiz, A. (1994) Food Res.

lefrero, S., Alzamora, S.M. and Gerscheson, L.N. (1994) J. Food Protec. (in press).

F.J. SALA, J. BURGOS, S. CONDÓN, P. LOPEZ and J. RASO

## 9.1 Historical perspective

Heat treatment and low temperature storage are at present amongst the main methods of food preservation.

Cold storage has the advantage of leaving nutritive value and organomieptic properties of foods almost unchanged. However refrigeration does not necessarily ensure food safety.

Heat, with its destructive effect on enzymes and microorganisms ensures safety and long preservation, but the effects of heat on foods can also be very detrimental. Some heat preservation processes cause significant reductions in nutritive value and drastic changes in organoleptic properties.

As no other method of food preservation to replace heat has yet been developed, a new approach in food preservation has arisen. This is the combination of heat with other methods that together enhance the lethal effect of heat on microorganisms and enzymes, and result in a lowering of the intensity of conventional heat treatments. This approach has lately revived the interest of scientists in what has become known as the preservation of foods by combined processes.

Although the preservation of foods by combined processes is not new the advance of scientific knowledge has opened new possibilities: the influence of different microenvironmental parameters on the heat resistance of microorganisms and enzymes is now much better known and new lethal effects of some physical phenomena have been reported. For example, the combination of heat and reduced pH to lower microbial hear resistance allowed the use of milder heat treatments and was one of the first combined processes to be employed. Other combinations widely used are those with sodium chloride, nitrite, etc. More recently, technological advances have led to the investigation of other possible combination. These include the combination of heat with ultrahigh pressures (Gould 1973), which is currently attracting the interest of many research ground worldwide and, most recently, the combination of heat with ultrasound

The idea of using ultrasound to speed up chemical reactions (known sonochemistry) and to inactivate microorganisms is not new. It was first

suggested at the beginning of this century (Harvey and Loomis, 1929). But the idea of enhancing the effect of heat by ultrasound, in order to reduce the severity of current heat processes, is new, and is now the main subject of our research group.

# 9.1.1 Heat inactivation of microorganisms and enzymes

### (a) Microorganisms

Although the preservation of foods by heat was first performed in France by Nicholas Appert around 1810, this remained for a long time an empirical practice until the scientific knowledge on the mechanism of the preservation effect began to accumulate. The works of Bigelow (1921) finally established the sound basis on which, still today, current methods of heat preservation rely.

The observation by Bigelow that the death of microorganisms followed a first order reaction kinetic pattern was essential for the tuture development of the technology of food preservation by heat. Bigelow showed that every unit of heating time of a microbial population at a given temperature educed the number of viable cells by a constant proportion. By plotting the log of the number of survivors as a function of heating times, a straight ine is therefore obtained. In this plot (survival curve), the minutes needed to reduce the number of viable cells to 1/10 (one log cycle) of its original salue is now known as the 'decimal reduction time', or  $D_t$  value. When the original Reduction Time Curve; DRTC), again a straight line is obtained. The number of degrees Celsius of temperature increase for the log  $D_t$  value of decrease by one log cycle is known as z value. The heat resistance of microorganisms is defined by these two parameters.

Once a  $D_t$  value is known, the kinetics of death (Survival curve) allows rediction of the numbers of survivors after a given heating time. Furthermore, as z value allow the calculation of the lethal effect of each temperate, the total lethal effect of any given process, including heating and coling phases, can be estimated, thus avoiding undue overprocessing. Work carried out during the last decades by food microbiologists on the muence of different factors on heat resistance of microorganisms and on

e kinetics of death, has led to some authors to question the validity of one published heat resistance data and that of the Bigelow's kinetics. It appears that heat resistance data  $(D_t)$  and z values), once considered well defined and constant parameters are in fact very variable, being fluenced by many factors. For example, the pH of heating menstruum one of the most important and one of the first to be known. But many hers, such as the water activity  $(a_w)$  (Alderton et al., 1980); sporulation thers, such as the water activity and Gerhardt, 1986; Condón et al., 1992b) and everyth medium (Donnelly and Busta, 1980), composition of heating

medium (Blocher and Busta, 1983; Condón and Sala, 1991) and incubation temperature and medium after heat treatment (Cook and Gilbert, 1968; Feeherry et al., 1987) have also been investigated.

Some heat resistance data reported in literature should therefore be accepted with caution as factors influencing these data were unknown to the authors or not taken into account. The effect of some influencing factors can be so big as to make the differences in heat resistance between two populations of the same strain, bigger than those between two unrelated species (Put and Aalbersberg, 1967).

The capacity of different parameters to strongly influence the hear resistance of microorganisms is today an important issue in thermobacterical places as are the deviations from theoretical death rate kinetics, such as those reported by some authors on survival curves and DRTC. Among different deviations reported on the patterns of survival curves (Moats et al., 1971; Brown and Ayres, 1975), 'tails' and 'shoulders' are the most frequent and best characterized. A combination of both can explain most if not all deviations of linearity of survival curves.

Tails' are end portions of survival curves that appear with a decreasing slope at the final stages of heating. A comprehensive review of the 'tails' phenomenon is that of Cerf (1977). The different hypotheses to explain this phenomenon have been classified by Cerf into two groups of theories from linearity of survival curves by postulating a different heat resistance a logarithmic death rate and blame the appearance of deviations to for each individual cell in a population. 'Mechanistic theories' assume methodological artefacts (Stumbo, 1973) or to the development of a higher heat resistance during heat treatments (Mackey and Derrick, 1986a). The development of a higher heat resistance of vegetative cells during heaf treatments, reported by different authors, would be due to metabolic can become the factor determining the intensity of heat treatments (Moats 'vitalistic' and 'mechanistic'. 'Vitalistic theories' try to explain deviations' changes (Mackey and Derrick, 1986b) or to interactions with the heating of heat treatments in order to improve the quality of food products has menstruum. Although the fraction of the population having a higher heaf resistance is normally very small, its heat resistance can be so high that et al., 1971; Condon et al., 1992a). Current concern to reduce the intensity led to a more detailed study of death rate kinetics and to model he treatments in such a way as to take into account deviations of logarithmic death rate (Cole et al., 1993).

'Shoulders', appear in the first portion of the survival curves, with different shapes. In 'shoulders' the slope of survival curves is always smaller and sometimes the number of survivors n tonly does not decrease but can even increase. This phenomenon is less frequent in vegetative cells and some authors have related it to cell clumps disgregation (Hansen and Riemann, 1963). 'Shoulders' are much more frequent in spore suspensions.

In some authors' opinions (Shull et al., 1963; Lewis et al., 1965), in spores, shoulders' are often caused by a lack of 'activation'. A high proportion of spore population is often unable to germinate. The spores are in a latent (dormant') state. Some chemical/physical treatments can 'activate' them, restoring their germination capacity. Heat is a well-known activation agent. During the first moments of a heat treatment two opposite phenomena therefore take place, each at a different rate and both catalysed by the activation of 'dormant spores' and the concurrent and subsequent mactivation of all spores. It is now believed that activation follows, as does heat inactivation, first-order reaction kinetics (Abraham et al., 1990; Sapru et al., 1993). The profile of shoulders would be determined by the balance between both rate constants.

In the last 30 years attempts have been made to develop mathematical models of death rates that would include 'shoulders'. Shull et al. (1963), the bis attempt to develop the first model, postulated that activation and heat inactivation were two separate and successive phenomena. This opinion was also shared by other authors (Abraham et al., 1990) who also postulated that activation is in fact the limiting factor of the inactivation phenomenon. On the contrary, other authors (Rodriguez et al., 1991; Sapru et al., 1992) believed that both phenomena are simultaneous and a prior 'activation' is not necessary for spores to be inactivated by heat. There is no agreement about whether the heat resistance of activated and commant spores is the same. While some have developed mathematical models assuming equal heat resistances (Rodriguez et al., 1991), the models of others assume that they are different (Sapru et al., 1993).

Other deviations of linearity of death kinetics in DRTC have also been geported. However, these are less known and there is no agreement among futhors. While some investigators have reported that z values increase at triangler temperatures of treatment (DRTC curves bend upwards) (Wang et al., 1964; David and Merson et al., 1990) others have reported that they decrease (Cerf and Hermier, 1973; Hermier et al., 1975). In some authors pinion (Cerf and Hermier, 1973) the decrease of D<sub>t</sub> values at high emperatures of treatment could be due to a thermal shock that would be greater the higher the temperature of treatment, causing the DRTC to gend downwards (decreasing z values). According to these authors the bigher D<sub>t</sub> and z values at higher temperatures reported in literature would be explained by methodological errors. Difficulties in the measurement of the very short heating times involve in high temperature treatments would itself in poor estimations of heating times. Much therefore remains innectain about heat resistance and death kinetics.

Despite substantial efforts carried out during the last half of this century, the mechanism(s) of heat inactivation are not yet clear. According to the first interpretation, the strict logarithmic order of death, as postulated by Bigelow, could most easily be explained by a mechanism involving the

destruction of one single or a small number of vital molecules per cell. A the kinetics of cell death have become better known many authors have attempted to explain deviations from linearity by implying in these mechanism different vital molecules and/or structures. Heat has been reported to damage different cell structures, including damage to commembranes, ribosomes, DNA, RNA and enzymes. DNA is still considered the most likely lethal target molecule, but damage occurring at the same time in different molecules and/or structures may also result in heat inactivation. Some of these injuries can be repaired and ultimately it is the balance of intensity of injury/capacity to repair that determines cell viability. A more detailed review of the mechanisms of microbial heat inactivation and injury is that of Gould (1989).

heat treatments for microbial destruction exceed those required for the which would add to the enzyme inactivation effect of heat with littlejuices, and those engaged in vegetable drying or freezing, which are ver limiting factor for long-term preservation of UHT milk (Cogan, 1977; Law inactivation of enzymes. However; there are some food industries, such as those involved in the production of citric juices, tomato pastes and concerned with the inactivation of endogenous deleterious enzymes. For example, a small fraction of orange pectinesterase that is highly hear effects on juice reconstitution from concentrates (Versteeg, 1979; Versteeg stabilization, the food industry is generally not concerned with it because et al., 1980). Extracellular proteases and lipases from psychrotrophic bacteria can be a problem in the dairy industry as they can become the 1979; Burton, 1988). For these food industries any combined treatment no damage to the nutritive value or sensory quality of the food woul (b) Enzymes. Although enzyme inactivation is often required for foot resistant is responsible for orange juice cloud loss and serious negative be valuable.

Active centres of enzymes consist of amino acid residues, usually the apart from each other in the primary structure, but brought together the native three dimensional structure of the macromolecule. A number of physical and chemical agents, such as heat, acidic or alkaline propresses, oxygen, chaotropic agents, etc. are capable of unfolding the molecule (Putman, 1954; Joly, 1965) disassembling the active centre and inactivating the enzyme. From the practical standpoint heat is the most important inactivating agent (Klibanov, 1983).

The native catalytically active structure is maintained by a delicated balance of different non-covalent forces, mainly ionic and hydrophobic interactions and hydrogen bonds. An increase in temperature diminished all these forces (except hydrophobic interactions, whose strength increase up to approximately 110°C; Privalov et al., 1986; Baldwin, 1986) inducing protein unfolding. Protein unfolding is thought to be the first step in help

Tayme inactivation (Tanford, 1968; Lapanje, 1978). While heat inactivation is an irreversible phenomenon, protein unfolding is a reversible one. The irreversibility of enzyme inactivation by heat is brought about by econdary events which are highly specific for individual enzymes. These econdary events can be divided into two groups (Klibanov, 1983): covaint and non-covalent changes. Covalent changes result in chemically deterd enzymes. Non-covalent changes consist of two types of transformations: polymolecular (aggregation) and monomolecular (incorrect folding). Son-covalent changes seem to be prevalent at low temperatures and close of neutral pH, whilst at high temperatures, long heating periods and extreme pH values, chemical changes appear to be involved. Aggregation askes place mainly in concentrated solutions.

Due to differences in the type and number of bonds and interactions yolved in maintaining the native conformation of the active centre and ther parts of the enzyme molecule and to the fact that they are not equally fected by heat and other protein unfolding agents, in a number of pizymes, inactivation occurs before noticeable conformational changes in be detected (Liang et al., 1990; Kelly and Price, 1991; Zhou et al., 93). On the contrary, in some instances, heat inactivation of enzymes and be preceded by extensive molecular unfolding (Dominguez et al.,

Enzyme resistance to heat inactivation is very dependent on environmental factors such as pH, ionic strength, soluble solids and presence of the denaturing agents. All these factors may, by themselves, induce inportant conformational changes which may not affect catalytic activity forminguez et al., 1992). However, they can modify the bonds and teractions playing the prevalent role of maintaining the macromolecular furture. These conformational changes influence heat resistance and the sture of the changes that heat can induce.

The heat inactivation of enzymes is generally considered as being a ggle-step, two-state (active-inactive) process. An alternative kinetic gdel has been proposed (Ray and Koshland, 1961) in which partially activated states, which retain fractional activity, have to be taken into ecount.

Single-step two-state processes follow first-order kinetics and there are try few instances in which heat enzyme inactivation has been shown to say that the non first-order process. Therefore two approaches can be blowed to analyse data obtained in enzyme heat inactivation experients. Residual enzyme activity can be plotted, either as it is done with rivial curves in thermobacteriology (see above) to obtain  $D_t$  and z values malternatively, data can be processed in accordance with the classical mations used in the study of first order chemical reactions. This way the mecourse of heat inactivation at constant temperature is expressed in these of rate constants (K) and the temperature dependence of the

### References

Abraham, G., Debray, E., Candau, Y. and Piar, G. (1990) Mathematical model of thermal destruction of Bacillus stearothermophilus spores. Applied and Environmental Microbi-

peroxide in the killing of microorganisms. Journal of Applied Bacteriology, 39, 31-40. ology, 56, 3073-80, hmed. F.I.K. and Russell, C. (1975) Synergism between ultrasonic waves and hydrogen

forms of Clostridium botulinum 62A spores over the water activity range 0 to 0.9. Applicates and Environmental Microbiology, 40, 511-15.

Alliger, H. (1975) Ultrasonic disruption. American Laboratory, 10, 75-85.
Atchley, A.A. and Crump, L.A. (1988) Acoustic cavitation and bubble dynamics. In Ultrasounds. Its chemical, physical, and biological effects (ed. K.S. Suslick), VCH Pub-

lishers, New York, pp. 1-64.

Baldwin, R.L. (1986) Temperature dependence of the hydrophobic interaction in protein folding. Proceedings of National Academic of Science, 83, 8069-72.

Beaman, T.C. and Gerhard, P. (1986) Heat resistance of bacterial spores correlated with

protoplast dehydration, mineralization and thermal adaptation. Applied and Environmental Microbiology, 52, 1242-46.

of General Microbiology, 22, 147-157.

Berlan, J. and Mason, T.J. (1992) Sonochemistry: from research laboratories to industrial Berger, J.A. and Marr, A.G. (1960) Sonic disruption of spores of Bacillus cereus. Journal

plants. Ultrasonics, 30, 203-212

Berliner, S. (1984) Application of ultrasonic processors. International Biotechnology Labora.

Bigelow, W.D. (1921) The logarithmic nature of thermal death-time curves. Journal of Infectious Diseases, 28, 528-532

Blocher, J.C. and Busta, F.F. (1983) Bacterial spore resistance to acid. Food Technology,

Boucher, R.M.G. (1978) Process for ultrasonic pasteurization. United States Patent, 4, 211

Brenner, D. (1990) Historical introduction to Sonochemistry. In Advances in Sonochemistry,

Vol. 1 (ed. T. Mason), Jai Press, London, pp. 1-37.

Brown K.L. and Ayres, C.A. (1985) Thermobacteriology of UHT processed foods. In Developments in Food Microbiology (ed. R. Davies), Applied Sciences Publishers. London, pp. 119-52.

Burgos, J., Ordonez, J.A. and Sala, F.J. (1972) Effect of ultrasonics waves on the hear resistance of Bacillus cereus and Bacillus licheniformis spores. Applied Microbiology, 2 Burleson, G.R., Murray, T.M. and Pollard, M. (1975) Inactivation of viruses and bacteria by ozone, with and without sonication. Applied Microbiology, 29, 340-4.
Burton, H. (1988) Ultrahigh-temperature Processing of Milk and Milk Products, Elseviel

Cerf, O. and Hermier, J. (1973) Thermoresistance anormale de spores bacteriennes chauffees Applied Science, London.

Cerf, O. (1977) Tailing of survival curves of bacterial spores. Journal of Applied Bacteriology, par injection directe dans la vapeur. Le lait, 43, 23-29

Chang, B.S., Park, K.H. and Lund, D.B. (1988) Thermal inactivation kinetics of horseradia peroxidase. Journal of Food Science, 153, 920-23

Coarkley, W.T., Brown, R.C., James, C.J. and Gould, R.K. (1973) The inactivation of enzymes by ultrasonic cavitation. Archiver of Biochemistry and Physics, 159, 722-29. Cogan, T.N. (1977) A review of heat resistant lipases and proteinases and the quality of dain

products. Journal of Food Science and Technology, 1, 95-105.
Cole, M.B., Davies, K.W., Munro, G., Holyoak, C.D. and Kilsby, D.C. (1993) A vitalistic model to describe the thermal inactivation of Listeria monocytogenes. Journal of Industria Microbiology, 12, 232-39.

Condon, S. and Sala, F.J. (1991) Heat resistance of Bacillus subtilis in buffer and foods of different pH. Journal of Food Protection, 55, 605-8.

# HEAT AND ULTRASOUND ON MICROORGANISMS AND ENZYMES 201

Condon, S., Garcia, M.L., Otero, A. and Sala, F.J. (1992a) Effect of culture age, preincubation at low temperature and pH on the thermal resistance of Aeromonas hydrophila.

Journal of Applied Bacteriology, 71, 322-6.
Condon, S., Bayarte, M. and Sala, F.J. (1992b) Influence of the sportulation temperature upon the heat resistance of Bacillus subtilis. Journal of Applied Bacteriology, 73, 251-6. Cook, A.M. and Gilbert, R.J. (1968) Factors affecting the heat resistance of B. stearothermophilus spores. Journal of Food Technology, 3, 385-93.

David, J.R. and Merson, R.L. (1990) Kinetic parameters for inactivation of Bacillus stearothermophilus at high temperatures. Journal of Food Science, 55, 488-93.

Davies, R. (1959) Observations on the use of ultrasound waves for the disruption of microorganisms. Biochimica et Biophysica Aca, 33, 491-93.

Davies, P.W., Greenhalgh, S.H., Donnelly, J.K. and Stentiford, E.I. (1992) Treatment of water. European Patent Application 0567225 A1.

DeGrois, X. and Baldo, X. (1969) Explanatory hypothesis of the absence of erosion, of

chemical effects and of sonoluminescence in true ultrasonic cavitation. Acustica Internat.

Dewhurst, E., Rawson, D.M. and Steele, G.C. (1986) The use of a model system to compare the efficiency of ultrasound and agitation in the recovery of Bacillus subtilis spores from polymer surfaces. Journal of Applied Bacteriology, 61, 357-363.

Dharkar, S.D. (1964) Sensitization of microorganisms to radiation by previous ultrasonic treatment. Journal of Food Science, 29, 241-3.

Dognon, A. and Simonot, Y. (1948) Actions des ultrasounds sur les suspensions. Influence de la concentration des particles. Comptes Rendue Academic Sciences, 227, 1234-42

(1992) Mechanisms of thermoinactivation of endoglucanase I from Trichoderma roseiii QM Dominguez, J.M., Acebal, C., Jimenez, J., Mata, A., Macarron, R. and Castillon, M.P. 9414. Biochemistry Journal, 287, 583-88,

Donnelly, L.S. and Busta, F.F. (1980) Heat resistance of Desulforomacularum nigrificans in soy protein infant formula preparations. Applied and Environmental Microbiology, 40, 727-5.

Pubs, C.A. (1966) Ultrasonic effects on isoenzymes. Clinical Chemistry, 12, 181-86.

El'Piner, I.E. (1964) Ultrasounds: Physical Chemical and Biological Effects, Consultants Dunn, F. and Macleod, R.M. (1968) Journal of Acoustic Society of America, 40, 932-40.

Bureau, New York, pp. 149-229.

Ell-Piner, I.E. and Surova, M.D. (1954) Acceleration of protein degradation process in an ultrasonic field. Doklady Akad Nauk SSSR, 94, 243-50. E. Bacillus sterarothermophilus spores. Applied and Environmental Microbiology, 53, 365-70. Gaboriaud, P.L.F. (1986) Stérilisation de liquides par ultrasons. French Patent 2 575 641 A1. Ganthavorn, C., Nagel, C.W. and Powers, J.R. (1991) Thermal inactivation of asparagus Recherry, F.B., Munsey, D.T. and Lowley, D.R. (1987) Thermal inactivation and injury of

Ipoxygenase and peroxidase. Journal of Food Science, 56, 47-9.
Garcia, M.L. (1985) Acción de los tratamientos 'ultrasonicos y térmicos en los esporos de B. subulis. Doctoral Thesis. Facultad de Veterinaria, Universidad Complutense, Madrid.

Garcia, M.L., Burgos, J., Sanz, B. and Ordonez, J.A. (1989) Effect of heat and ultrasonic waves on the survival of two strains of Bacillus subtilis. Journal of Applied Bacteriology, Jould, G.W. (1973) Inactivation of spores in food by combined heat and hydrostatic pressure. Acta Alimentaria, 2, 377-83.

fould, G.W. and Dring, G.J. (1975) Heat resistance of bacterial endospores and concept of an expanded osmoregulatory cortex. Nature, 258, 402-5

jould, G.W. (1989) Heat-induced injury and inactivation. In Mechanisms of Action of Food Preservation Procedures (ed. G.W. Gould), Elsevier Applied Science, London, pp. 11-42. Itabar, P., Voinovitch and Prudhome, R.O. (1949) Action des ultrasonides sur une oxidase. Biochemica et Biophysica Acta, 3, 412-17.

ansen, N.J. and Riemann, H. (1963) Factors affecting the heat resistance of nonsporting arvey, E. and Loomis, A. (1929) The destruction of luminous bacteria by high frequency organisms. Journal of Applied Bacteriology, 20, 314-18.

sound waves. Journal of Bacteriology, 17, 373-9.

supersonic vibrations. A. (1932) High speed photomicrografy on living cell subjected to supersonic vibrations. Journal of General Physiology, 15, 147.

Hermier, J., Begue, P. and Cerf, O. (1975) Relationship between temperature and sterilising efficiency of heat treatments of equal duration. Experimental testing with suspensions of espores in milk heated in an ultra-high-temperature sterilizer. Journal of Dairy Research

Jacobs, S.E. and Thornley, M.J. (1954) The lethal action of ultrasonic waves on bacteria suspended in milk and other liquids. Journal Applied Bacteriology, 17, 38-55. Hughes, D.E. and Nyborg, W.L. (1962) Cell disruption by ultrasound. Science, 138, 108–14.

foly, M. (1965) A Physicochemical Approach to Denaturation of Proteins, Academic Press,

Kashkooli, H., Roony, J. and Rooxby, R. (1980) Effects of ultrasound on catalase and

malatedehydrogenaec. Journal of Acoustic Society of America, 67, 1798–1801.

Kelly, S.M. and Price, N.C. (1991) The unfolding and refolding of pig heart fumarase.

Biochemical Journal, 275, 745-49.

Kinsloe, H., Ackerman, B. and Reid, J.J. (1954) Exposure of microorganisms to measured sound fields. Journal of Bacteriology, 68, 373-80.

Klibanov, A. (1983) Stabilization of enzymes against thermal inactivation. Advances in Applied Microbiology, 29, 1-28.

Kruus, P. (1991) Sonochemical initiation of polymerization. In Advances in Sonochemistry, vol. 2 (ed. T.J. Mason), JAI Press, London, pp. 2-21.

Apanje, S. (1978) Physicochemical Aspects of Protein Denaturation, Wiley, New York.

Law, B. (1979) Reviews of the progress of dairy science. Enzymes of psychotrophic bacteria

Lee, B.H., Kermasha, S. and Baker, B.E. (1989) Thermal ultrasonic and inactivation of Lepeschkin, W.W. and Golman, D.E. (1952) Effects of ultrasound on cell structure. Journal Salmonella in thin films of aqueous media and chocolate. Food Microbiology, 6, 143-42. and their effects on milk and milk products. Journal of Dairy Research, 46, 573-88.

of Cellular Composition and Physiology, 40, 393-97.
Lewis, J.C., Snell, N.S. and Alderton, G. (1965) Dormancy and activation of bacterial spores. In Spores III (eds L.L. Campbell and H.O. Halvorson), American Society for

Microbiology, Washington, D.C., pp. 47-55. Lopez, P., Sala, F.J., Fuente, J.L., Condon, S., Raso, J. and Burgos, J. (1994) Inactivation of peroxidase, lipoxygenase and polyphenoloxidase by manotermosonication. Journal of son of inactivation and conformational changes of D-glyceraldehyde-3-phosphate dehy drogenase during thermal inactivation. Biochimica et Biophysica Acta, 1038, 247-52. Agriculture and Food Chemistry, 42, 552-56.

Lu, A.T. and Whitaker, J.R. (1974) Some factors affecting rates of heat inactivation and teactivation of horseradish peroxidase. Journal of Food Science, 39, 1173-78.

Luca, R. and Zamfirescu-Georgiu, M. (1970) Ultrasonic effect on some physico-chemical properties of serum proteins and enzymes. Revue Rumaine Medicine Interne, 7, 421-25. typhimurlum during heating at rising temperatures. Letters in Applied Microbiology, Mackey, B.M. and Derrick, C.M. (1986a) Elevation of the heat resistance of Salmonella

Mackey, B.M. and Derrick, C.M. (1986b) Elevation of the heat resistance of Salmonella typhimurium by sublethal heat shock. Journal of Applied Bacteriology, 61, 389-93.

Mason, T.J. and Lorimer, J.P. (1988) Sonochemistry: Theory, Application and User of Ulrasound Chemistry, Ellis Horwood, Chichester, pp. 42-47.

Matsudaira, M. and Sato, A. (1933) Effect of supersonic ray on enzymes. Tohoku Jourid Mason, T.J. (1993) Sonochemistry: A technology for tomorrow. Chemistry and Industry

and lactate dehydrogenase solutions. Journal of Acoustic Society of America, 42, 527-299 Mett, H., Schacher, B. and Wegman, L. (1988) Ultrasonic disintegration of bacteria min of Experimental Medicine, 22, 412-16.
McCleod, R.M. and Dun, F. (1967) Effects of ultrasonic cavitation on trypsin, chymotrypai lead to irreversible inactivation of lactamase. Journal of Antimicrobial Chemotherapy, 2 Moats, W.A., Dabbah, R. and Edwards, V.M. (1971) Interpretation of nonlogarithmic

survivor curves of heated bacteria. Journal of Food Science, 36, 523-6.
Naimark, G.M. and Mosher, W. A. (1953) Effects of sonic vibration on the proteolytic activity of pepsin. Journal of Acoustic Society of America, 25, 289.

# HEAT AND ULTRASOUND ON MICROORGANISMS AND ENZYMES

Neppiras, E.A. (1980) Acoustic cavitation. Physics Reports, 61, 159-251.
Oparin, A.I., Bardinskaya, M.S. and El'Piner, I.E. (1954) Action of ultrasonic waves on yeast invertase. Doklady Akad Nauk SSSR, 99, 423-432.

Ordoficz, J.A., Sanz, B., Hernandez, P.E. and Lopez-Lorenzo, P. (1984) A note on the effect of combined ultrasonic and heat treatments on the survival of thermoduric streptococci. Journal of Applied Bacteriology, \$6, 175-77.

Ordonez, J.A., Aguilera, M.A., Garcia, M.L. and Sanz, B. (1987) Effect of combined ultrasonic and heat treatment (thermoultrasonication) on the survival of a strain of Suphylococcus aureus. Journal of Dairy Research, 54, 61-7.
Ordonez, J.A., Burgos, J., Raso, J., Lopez, P., Condon, S. and Sala, F.J. (1992) Procedi-

miento para la destrucción de microorganismos y enzimas: Proceso-MTS. Spanish Patent

released to ultrasonic treatment from Bacillus stearothermophilus spores. Journal of Applied Bacteriology, 71, 445-51. Palacios, P., Burgos, J., Hoz, L., Sanz, B. and Ordoffez, J.A. (1991) Study of substances Paci, C. (1953) L'emploi des ultra-sons pour l'assainissement du lait. Le Lair, 33, 610-15.

Pethric, R.A. (1991) Ultrasonic studies of polymeric solids and solutions. In Advances in

Privalov, P.L., Griko, Y.V., Venyamino, Y.S. and Kutyshenko, V.P. (1986) Cold denaturation of myoglobin. Journal of Molecular Biology, 19, 487-98.

Prudhome, R.O. and Grabar, P. (1947) Etude de la denatuartio des proteides. I. Action des Sonochemistry, vol. 2 (ed. T. Mason), Jai Press, London, pp. 66-129.
Price, G.J. (1990) The use of ultrasound for the controlled degradation of polymer solutions.
In Advances in Sonochemistry, vol. 1 (ed. T.J. Mason), Jai Press, London, pp. 231-287.

US sur les proteides du serum de cheval normal et sur les acides aminès cycliques. Bulletin Societé Chimie Biologie, 29, 122-33.

Put, H.M. and Aalbergsberg, W.I.J. (1967) Occurrence of Bacillus subtilis with high heat resistance. Journal of Applied Bacteriology, 30, 411-19.

K. Bailey), Academic Press, New York, pp. 808-92.
Ray, W.J. and Koshland, D.B. Jr. (1961) A method for characterizing the type and number Putman, F.W. (1954) Protein denaturation. In The Proteirs, Vol. 1B (eds H. Neurath and

of groups involved in enzyme action. Journal of Biological Chemistry, 236, 1973-1979.
Rodriguez, A.C., Smerage, G.H., Teixeira, A.A., Lindsay, J.A. and Busta, F.F. (1991)
Population model of bacterial spores for validation of dynamic thermal processes. Journal of Food Process Engineering, 15, 1-30.

Santamaria, L., Castellani, A. and Levi, F.A. (1952) Hyalurodinase inactivation by ultrasonic waves and its mechanisms. Enzymologia, 15, 285-95.

cheat resistance of Bacillus recorderations. (1902) Eucet of ultrasonic waves on the of Bacterial Spores (eds G.J. Dring, D.J. Ellar and G.W. Gould), Academic Press, New Spru, V., Teixeira, A.A., Smerage, G.H. and Lindsay, J.A. (1992) Predicting thermophilic spore population dynamics for UHT sterilization processes. Journal of Food Science, 57, 1248-57. lanz, B., Palacios, P., Lopez, P. and Ordonez, J.A. (1985) Effect of ultrasonic waves on the

tive models for bacterial spore population responses to sterilization temperatures. Journal apru, V., Smerage, G.H., Teixeira, A.A. and Lindsay, J.A. (1993) Comparison of predicof Food Science, 58, 223-8.

cherba, G., Weigel, R.M. and O'Brien, J.R. (1991) Quantitative assessment of the germicidal efficacy of ultrasonic energy. Applied and Environmental Microbiology, 57,

of bacterial spores. Applied Microbiology, 11, 485-7.
ierra, G. (1972) Sterilization with gluteraldehyde. United States Patent 3,697,222.
itumbo, C.R. (1973) Thermobacteriology in Food Processing2, 2nd edn, Academic Press, hull, J.J., Cargo, G.T. and Brnst, R.R. (1963) Kinetics of heat activation of thermal death

uslick, K.S. (1988) Homogeneous sonochemistry. In Ultrasounds. Its Chemical, Physical anford, C. (1968) Protein denaturation: part C characterization of the denaturate state. In and Biological Effects (ed. K.S. Suslick), VCH Publishers, New York. uslick, K.S. (1989) The chemical effects of ultrasound. Scientific American, 2, 62-8.

Advance in Protein Chemistry, vol. 23. Academic Press, pp. 121-282.

Utsunomiya, Y. and Kosaka, Y. (1979) Application of supersonic waves to foods. Jour of Faculty of Applied Biological Science, 18, 225-31.

Versteeg, C., Pectinesterases from orange juice - their purification, general characteristics and juice cloud destabilizing properties. PhD Thests. Agricultural University, Wageninger, The Netherlands.

fersteeg, C., Rombouts, F.M., Spaansen, C.H. and Plinik, W. (1980) Thermostability and orange cloud destabilizing properties of multiple pectinesterases from orange. Journal of Food Science, 45, 969-988.

Wang, D.I., Scharer, J. and Humphrey, A.E. (1964) Kinetic of death of bacterial spores at

elevated temperatures. Applied Microbiology, 12, 451-54.
Weissler, A. (1960) Effects of ultrasonic irradiation on hemoglobin. Journal of Acounti Society of America, 32, 1208-12.

Society of America, 22, 120-12.
Williams, A.R., Stafford, D.A., Callely, A.G. and Hughes, D.B. (1970) Ultrasonic dispersal convinced studies flowed from Journal of Amilied Bacteriology, 33, 656-63.

of activated sludge flocs. Journal of Applied Bacterlology, 33, 656-63.
Winter, E. (1971) Hitzebestandigkeit der peroxidase. Z. Lebensm Unters. Forsch, 145, 3-65.
Zhou, H.M., Zhang, X.A., Ying, Y. and Tsou, C.L. (1993) Conformational changes at the active site of creatine kinase at low concentrations of guanidine chloride. Biochemical Journal, 291, 103-7.

## Electrical resistance heating of foods P. FRYER

### 10.1 Introduction

Electrical resistance heating allows particles and liquids to heat at the same fate and permits the rapid heating of mixtures of high solids fractions. The fechnique has been applied to a number food processes, and has recently been developed into a commercial process for the st rilisation of food mixtures. To understand the process, it is necessary to study food electrical conductivity and predict the resulting heating patterns. Models for the process are discussed, and the ways in which electrical processing may differ from conventional thermal sterilisation suggested.

## 1.1 The thermal sterilisation of foods

he use of heating for reducing numbers of microorganisms in foods is widespread [1]. Such foods, supplied to the consumer, must be commerially sterile, and so the aim of thermal processing is to reduce the level f any microbial contamination to the point where the food will not cause thealth hazard or undergo spoilage, at any point during its life. Two types freactions occur within a food when it is heated; those which reduce the evel of microbial contamination and those which result in losses in product hality, in terms of nutrition, taste and texture. The classical method of fermal preservation is the canning process, in which food is placed in the ckage, which is then sealed and sterilised within batch or continuous iorts. The commonest method of providing heat to the can is the use of indensing steam. Heat must then be transferred within the can, either by ermal conduction if the food is a solid or a very viscous liquid, or by Invective heat transfer if the food is a less viscous liquid. When processing can or a package, it is necessary to sterilise every part of the food. This in lead to overcooking of some or all of the material, as a result of the owness of heat transfer.

In practice, canned food has a taste and texture significantly different to improcessed foods. Whilst some canned products, such as tinned beans or of phato soup, have achieved wide acceptance, there is a commercial ovantage in improving the quality of much canned food. Optimising the ballity of packaged food is complex [2]. A number of techniques have been used to increase the quality of packaged food; these include rotating

### PROCESSING TECHNOLOGIES

### Reducing Process Variation in the Cooking and Smoking Process

### **ROBERT E. HANSON\***

We are lost in the mazes of our ingenuities because, being trained to look at the details rather than the holes, we are confused by the complexity we have created.

— Arnold Pacey, MIT professor

### Introduction

Converting meat from non-uniform live animals into uniform-quality meat products is a complex task. To be successful, processors must thoroughly understand the myriad processes that go into manufacturing processed meat products. At every step, variation must be measured and controlled to reduce its impact on product costs and quality.

Once a meat product goes into production, processors generally have the same objective — to manufacture consistent-quality products at the lowest possible cost. For production, the goal is not to change the product quality, but rather to make it the same every time. Reducing variation during manufacturing is essential to control costs and quality.

As scientists, we are trained to identify and solve problems through experimentation. We don't often get the chance to step back and examine the entire manufacturing process to identify the holes that need fixing. To reduce the impact of product variation, however, we must do exactly that identify the sources of variation and establish methods for measuring and controlling them. Even better, we may find ways of not just controlling variation, but actually eliminating it.

### Losses in the Meat Supply Chain

Typical losses in the meat supply chain are shown in Table

Weight losses occur in every step of the meat supply chain for many different reasons. For the processor, the following

losses may occur because of variation in the cook/chill process:

- Inability to formulate/pump to regulatory limits
- Cooking losses (cooking shrink)
- Cooling losses (cooling shrink)
- Slicing losses
- Package overfill
- Product defects
- Rework

This paper examines the measurement, control, and reduction of losses related to the cooking, smoking, and chilling processes.

### Impact of Process and Product Variati n

Process variation during cooking, smoking, and chilling causes variation in the color, weight, and composition of the finished product. This variation results in increased manufacturing costs and variable quality.

Inconsistent color or color defects may result in downgraded product or rework. Variable piece weights cause package weight variation and overfill. Variation in finishedproduct composition (protein, fat, water) makes it more difficult to formulate or pump to USDA regulatory limits for fat and added-water.

### Cook/Chill Variation

During cooking, non-uniform oven temperatures and air velocities cause uneven heating and drying rates, resulting in variable product temperatures, weight, composition, and color.

During chilling, non-uniform cooler temperatures and air velocities cause variable product temperatures, weight, and composition, but do not usually affect color.

### **Stuffing and Slicing Variation**

Cooking and chilling are not the only sources of weight variation. The stuffing process also contributes to piece weight variation.

For linked products, link-weight variation is a combination of stuffer, oven, and cooler variation as follows:

<sup>\*</sup>Robert E. Hanson, Manager of Technical Development, Alkar, 932 Development Drive, Lodi, Wisconsin 53555.

Reciprocal Meat Conference Proceedings, Volume 50, 1997

TABLE 1. Typical Losses in the Meat Supply Chain.

Livestock Producer	Livestock Hauler	Meat Packer	Meat Processor	Distributer & Retailer	
Poor feed conversion	Deaths	Yard deaths Inability to pump/ formulate to regula limits		Product damage in transit	
Deaths	Crippling	Condemnations	Cooking shrink	Spoiled in code	
Disease	Stress	PSE meat	Cooling shrink	Fading	
Genetic deficiencies	Injuries	Excessive trim	Slicing losses	Theft	
Breed deficiencies		Failure to maximize available cuts	Package overfill	Overage product	
Nutrient control		Floor scrap	Product defects		
Timing	•	Overage product	Rework	-	
•		Poor grading	Packaging defects		
		By-product recovery and sale	Overage distress		
		Poor boning yields	Contamination & foreign objects		
		Failure to use mechanical separation	Raw material shrink		
			Loss of exudate		

<sup>\*</sup>adapted from Thompson (1995)

Link-weight variation = stuffing variation + oven-shrink variation + cooler-shrink variation (for linked sausages)

For sliced products, most slicers automatically adjust onthe-fly to control slice weights and package weights. Even so, excessive product variation from uneven stuffing, cooking, or cooling makes it harder for the slicer to do its job accurately. Stuffing variation causes non-uniform end-to-end diameters and variable product density. Cooking variation may cause non-uniform product diameters. Cooling variation causes inconsistent slicing temperatures.

### **Composition Variation**

Shrink variation during cooking and cooling causes variable finished-product composition (protein, fat, water). For sausage products such as frankfurters and bologna, the blend-to-blend variation of raw materials also contributes to composition variation. For cured meats such as bacon and ham, uneven injection of curing solutions causes composition variation.

### **Cost of Finished-Product Variation**

Finished-product variation is a huge cost to the meat industry. The primary costs of product variation are —

- Package-overfill giveaway
- Product-composition giveaway
- Quality downgrades

Overfill and composition giveaway are repeated errors that are easily measured and quantified. Quality downgrades occur more sporadically and therefore are difficult to measure accurately.

### Cost of Overfill- and Composition-Giveaway in Frankfurter Production

The following example shows the estimated cost of overfill and composition giveaway for a U.S. frankfurter manufacturer.

### **Overfill Giveaway**

Due to stuffing variation and cook/chill shrink variation, not all frankfurter links are exactly the same weight. This link-to-link weight variation causes variable package weights. To avoid underweight packages, processors usually set the target package weight slightly higher than the marked weight. The difference between the average package weight and the marked weight is called the overfill giveaway, and is calculated as follows:

Overfill giveaway = average package weight - marked package weight

The overfill needed to avoid underweight packages depends on the average weight and standard deviation of the individual links (LaBudde, 1991). Increased link-to-link weight variation requires a larger overfill giveaway to avoid underweights.

For example, suppose the marked package weight is 1.0 lb/package for a U.S. product. Depending on the link-weight variation, the processor might target the average package weight at 1.02 lb/package to avoid underweights. The overfill giveaway, then, is 0.02 lb/package or 2.0%. If the product cost into the package is \$0.75/lb, the annual overfill cost for a processor that manufactures 60 million lb/yr of frankfurters would be calculated as follows:

Overfill giveaway cost = 60 million lb/yr x .02 lb over fill/lb product x \$0.75/lb = \$900,000/year

To cut the cost of overfill giveaway, the variation in stuffed weights and cook/chill shrinks must be reduced to decrease the link-to-link weight variation. The target average weight can then be moved closer to the marked package weight to reduce overfill giveaway.

### **Composition Giveaway**

Composition giveaway for frankfurters is caused by undershooting the USDA limits for fat and added-water in the final product. To avoid compliance violations, processors typically set targets for fat and added-water content slightly under the USDA limits. Variation in blend-to-blend raw material composition and uneven cook/chill shrinks create variation in the final-product composition, making it harder to target the compliance limits accurately.

The composition giveaway needed to avoid compliance violations depends on the average undershoot and standard deviation of the final-product composition (LaBudde, 1991). Increased variation in the final-product composition requires a larger composition giveaway to avoid compliance violations.

The cost of composition giveaway depends on the average undershoot and the penalty cost for undershooting (LaBudde, 1991). For example, the USDA limits for a full-fat frankfurter formula are 30% fat + 10% added-water for a total of 40%. To avoid compliance violations, a processor might target an average composition of 38.5% for fat plus added-water — 1.5% under the 40% limit. If the penalty cost for this product was \$0.005 /lb/% undershoot, the composition giveaway would be calculated as follows:

Composition giveaway cost =  $60 \text{ million lb/yr} \times (\$0.005/\text{lb/} \times 1.5\%)$ = \$450,000/yr

To cut the cost of composition giveaway, variation in raw material blends and cook/chill shrinks must be reduced to decrease the variation in final-product composition. The targets for fat and added-water can then be moved closer to the USDA limits to reduce composition giveaway.

### **Total Giveaway Cost**

The total costs of overfill plus composition giveaway for this example are calculated as follows: Total giveaway cost = overfill-giveaway cost + composi tion-giveaway cost

= \$900,000/yr overfill cost + \$450,000/yr composition cost

= \$1.35 million/yr

The LaBudde (1991) reference includes further examples explaining the cost of product variation.

### **Influence of Cooking Equipment and Processes**

Equipment design, cooking processes, and heating media all have a strong effect on process and product variation. The influence of these factors must be understood to evaluate their importance in reducing variation.

### **Cooking Equipment**

The meat industry uses many different types of production cooking systems in both batch and continuous designs. Although equipment designs vary widely, only the following four heating media are commonly used:

- Air (free- and forced-convection)
- Steam
- Hot water
- Microwave

A countless variety of meat products are cooked using forced-air convection ovens (smokehouses), steam cabinets, and hot-water cookers. Microwave cooking, however, has gained only limited industry acceptance because of the shallow penetration depth and uneven heating of microwaves. Industrial microwave ovens have generally been confined to applications for thin products such as the continuous cooking of sliced bacon.

### **Steam and Hot-Water Cooking**

For steam and hot-water cooking, products are usually stuffed in plastic casings or stainless steel molds and then cooked in steam cabinets, hot-water tanks, or continuous systems.

Steam and hot-water cooking are simple processes with only two variables — cooking time and cooking temperature. Because condensing steam and hot water are both extremely effective at transferring heat to the product surface, products cooked at the same temperature in either steam or hot water will have approximately the same cooking time (Heldman, 1975). Steam and hot-water temperatures within a steam cabinet or water-cook tank are typically very uniform, and therefore product temperatures are also very uniform.

### **Forced-Air Convection Cooking**

In forced-air convection ovens (smokehouses), products are heated using fan-driven air. Batch oven capacities range widely from small ovens that hold 100–200 kg/batch to large ones that hold up to 25,000 kg/batch. For continuous systems, production capacities commonly range from 200 kg/

### TABLE 2. Potential Sources f Temperature, Shrink, and Color Variation f r Meat Products Cooked in Batch Ovens.

### Variation within ven

- Top-to-bottom
- Side-to-side
- Front-to-back

### Batch-to-batch variation among ovens

- Multiple ovens
- Different height, width, and length
- Different designs
- Different ages
- Different operators for different ovens over multiple shifts
- Inconsistent loading practices
- Variable lag times between cooking and cooling

### Oven maintenance

- Out-of-balance airflow
- Control system out of calibration
- Inadequate maintenance of major components (eg. main fan, exhaust fan, gas burner or steam coil, fresh-air and exhaust dampers, control system, rotating dampers)

### Differences in operator training and experience

Different levels of training, experience, and capabilities among operators and supervisors

### Poor ptimization of cooking processes

- Processes designed for "worst-case" ovens
- Processes are drier than necessary to "be on the safe side"

hr for beef-jerky systems to 7,000 kg/hr for wiener systems to 10,000 kg/hr for bacon systems.

Regardless of the size, shape, design, or age of an oven, all forced-air cooking processes have the same four cooking variables

- Cooking time
- Dry-bulb temperature
- Wet-bulb temperature
- Air velocity

When meat products in moisture-permeable casings or without casings are cooked in forced-air convection ovens, heat transfers from the air to the product while, at the same time, moisture evaporates from the product to the air (Bengtsson et al., 1976). This process is known as simultaneous heat and mass transfer. Moisture evaporating from the product surface causes evaporative cooling, and this evaporative cooling strongly influences product drying rates and cooking times (Godsalve et al., 1977; Hanson, 1988; Skiöldebrand, 1980).

A typical air-handling system and airflow pattern for batch meat-processing ovens is shown in Figure 1.

As shown in the diagram, the recirculated air is supplied to the oven cabinet through the supply ducts, driven through the product zone, and then drawn back through the return duct into the fan cabinet. The air is reheated in the fan cabinet and recirculated through the oven. Although the airflow patterns are very turbulent, the air is driven through the product zone in a generally bottom-to-top direction. The supply

### FIGURE 1.



Batch Oven Airflow.

air is the hottest air in the oven. The return air, having been drawn through the cold product, is the coolest air in the oven.

### Sources of Shrink Variation in Batch Ovens

Potential sources of shrink, temperature, and color variation in batch ovens are shown in Table 2.

Meat products are stationary in batch ovens, and therefore have temperature and shrink variation in all three dimensions of the oven as follows:

- Side-to-side
- Top-to-bottom
- Front-to-back

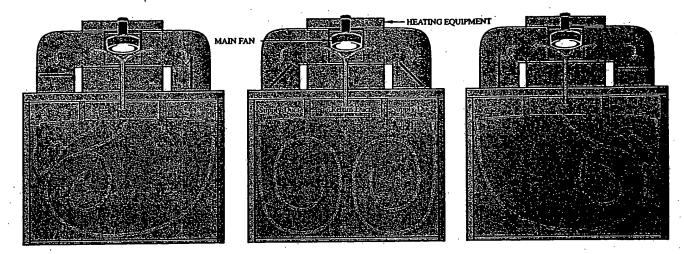
Although product variation can be reduced by adjusting and balancing the airflow, some variation will always exist.

To reduce side-to-side and top-to-bottom variation, most batch ovens are equipped with a rotating-damper system that continuously sweeps the air from side-to-side during cooking (Figure 2). This side-to-side sweeping action is known as "moving-front" or "oscillating" airflow. The rotating-dampers can be adjusted to balance the airflow from side-to-side and top-to-bottom.

To reduce front-to-back variation, the oven return ducts usually have adjustable slides that can be opened or closed to balance the airflow from front-to-back.

Although the rotating dampers create a moving front of air, the general direction of the air through the product zone is still from bottom-to-top (Figures 1 and 2). Because the air cools as it travels through the product, the supply air is hotter that the return air. As a result, the product in the topcenter of the oven is the coolest and has the lowest cooking shrink, and the product in the bottom corners is the hottest and has the highest cooking shrink.

### FIGURE 2.



Oscillating Oven Air Flow.

If an oven is very tall or wide, the air has a longer path from the supply to the return ducts, and therefore it cools down more as it travels through the product zone. For this reason, the dry-bulb temperature drop from the supply to return ducts is generally greater for large ovens than for small ones. As a result, given the same product and process, the product temperature and shrink variation are generally greater in a large oven than in a small one.

In addition to oven design and size, several other factors contribute to shrink variation for products cooked in batch ovens (Table 2). A major cause of batch-to-batch variation among ovens is simply that different employees operate multiple ovens over multiple shifts. Different levels of experience, training, and capabilities among operators will cause inconsistent shrinks and color from batch-to-batch.

Oven maintenance also plays a key role in controlling shrink variation. Components such as control systems, intake and exhaust dampers, rotating dampers, main and exhaust fans, fan belts, gas burners, steam and humidity valves, gaskets and others must be properly calibrated, balanced, and maintained to provide consistent performance among ovens.

Another major factor contributing to shrink variation is poor optimization of batch cooking processes. Processors with many ovens of different ages and designs often develop cooking processes that target their "worst-case" ovens, thus overcooking many loads and creating unnecessary load-to-load shrink variation. Furthermore, meat products are often cooked using overly-conservative processes that are drier than necessary to prevent problems such as fat separation and color streaking. In other words, processes are often designed to "be on the safe side." Because dry cooking processes inherently create more variation than humid ones, this practice contributes to unnecessary shrink and color variation.

### **Reducing Product Variation**

Shrink variation that occurs during cook/chill processes can be reduced in many ways, including the following:

- Upgrading to electronic controls
- Optimizing oven designs
- Using good loading practices
- Optimizing cook/chill processes
- Training operators, supervisors, and maintenance
- · Cooling products immediately after cooking
- Using low-shrink cooling methods
- Converting from batch to continuous processing

These methods of reducing product variation are further explained below.

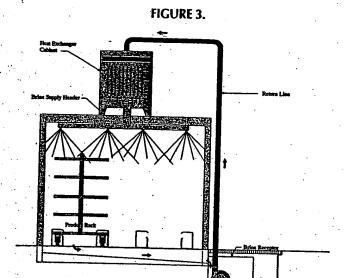
### **Electronic Controls**

The widespread adoption of electronic controls in place of older-technology pneumatic controls has reduced total shrink and shrink variation in batch ovens. Electronic controls improve the repeatability of cooking processes from batch-to-batch. They are also more accurate and stay in calibration for much longer than pneumatics, thus reducing shrink variation caused by control system miscalibration.

### Oven Design & Product Loading

As previously stated, the temperature, shrink, and color variation are generally greater for large ovens than for small ones. In factories with multiple ovens, however, the load-to-load variation among ovens is usually greater than the variation within ovens (LaBudde, 1989). In processing system layouts, therefore, the installation of fewer, larger ovens of matching design and size will generally reduce batch-to-batch variation.

Good loading practices reduce product variation. Ovens should be loaded with adequate clearance between the product and the side walls and floor. For most ovens, adequate



clearance is 30 cm. This spacing allows the moving front of air to travel unimpeded from side-to-side in the oven. For partial loads, the oven should be loaded evenly from front-to-back to maintain balanced airflow along the length of the oven.

### **Optimization of Cook/Chill Processes**

Liquid Brine Chiller.

In a previous RMC paper, I explained the principles of heat and moisture transfer in meat products during cooking (Hanson, 1990). A good understanding of these principles is necessary to develop optimized cooking processes.

As previously stated, the following variables are used to control oven cooking processes: cooking time, dry-bulb temperature, wet-bulb temperature, and air velocity. Typically, the first one-half to three-quarters of a cooking process for smoked meats is used to develop quality characteristics such as smoke color, internal color, skin set, and texture. After the desired quality characteristics are achieved, the product is heated to its target core temperature. Cooking processes must be optimized to balance quality characteristics with cooking time and shrink.

### C oling Methods

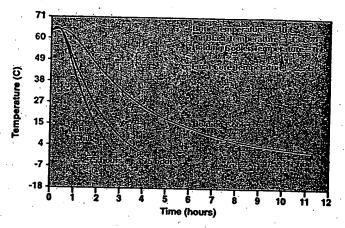
After the product is cooked, immediate and rapid chilling helps prevent excessive cooler shrinks and shrink variation. When hot products are removed from an oven, moisture evaporates rapidly from the hot product surfaces. After the surface is cool, the evaporation rate drops off dramatically.

In an air cooler, uneven cooling and drying causes variable cooler shrinks within a batch. If the holding times in the cooler vary widely from batch-to-batch, the variable holding times will cause cooler-shrink variation among batches.

Brine chillers are often used for rapid cooling of meat products (Figure 3). Here, a prechilled sodium-chloride brine

### FIGURE 4.

### Brine vs. Blast vs. Cool r 3.2 Kg Pressed Ham, 90mm x 150mm x 250mm



solution (usually -4 to -12°C) is showered over the product to cool it. Products that are brine chilled generally have no cooler shrink or shrink variation.

The cooling curves for hams cooled in a brine chiller, blast chiller, and holding cooler are shown in Figure 4. Temperature setpoints for the trials represented cooling temperatures typically used in the industry. The average air velocities were approximately 5 m/s for the blast chiller and 0.5 m/s for the holding cooler.

As shown in Figure 4, to cool the hams to a 2.5°C core, the brine chiller had the shortest cooling time of 2.75 hours, followed by the blast chiller at 3.75 hr and the holding cooler at 11 hr.

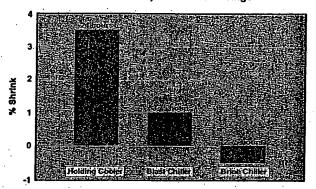
Cooler shrinks for hams chilled using the three cooling methods are shown in Figure 5.

The holding-cooler hams had the highest cooler shrink at 3.5%, followed by the blast-chilled hams at 1%. In the brine chiller, the hams actually gained weight (+0.5%) by absorbing brine. However, most of this absorbed brine was subsequently lost by drip-off and evaporation while tempering in a holding cooler. The net cooler-shrink for the brine-chilled hams was therefore approximately 0%.

Fellows (1988) stated that high-velocity air causes faster drying rates than low-velocity air. Accordingly, since the blast chiller had a higher air velocity that the holding cooler, it theoretically should have caused more drying and a higher cooling shrink. As shown in Figure 5, however, the cooling shrink was lower for the blast-chilled hams than for the holding-cooler hams. The faster cooling of the blast-chilled hams most likely caused this apparent contradiction. As the product surfaces cooled, the moisture would have evaporated less readily from the blast-chilled product. Therefore, the faster cooling of the blast-chilled hams would have made them less prone to evaporation for much of the cooling process, resulting in a lower cooling shrink.

### FIGURE 5.

### Cooler Shrink Comparisons Retail Hams, Permeable Casings



**Cooling Methods** 

### **Continuous Processing**

Converting from batch to continuous processing generally results in major reductions in product variation. Many of the sources of batch oven variation listed in Table 2 are reduced or eliminated in continuous systems.

The conveyer designs in continuous systems inherently eliminate variation in one or more of the batch oven dimensions — front-to-back, side-to-side, or top-to-bottom.

For example, a "tunnel" continuous system for small sausages is shown in Figure 6. In this system, a chain conveyer carries sausages through the oven from front-to-back — eliminating front-to-back variation.

A "horizontal-serpentine" continuous oven for small sausages is shown in Figure 7. In this system the conveyer turns back on itself as it carries the product through the oven — eliminating front-to-back and side-to-side variation.

A "vertical-serpentine" continuous oven is shown in Figure 8. The conveyer in this system carries the product up and down through the oven — eliminating front-to-back and top-to-bottom variation.

Continuous systems reduce or eliminate many other sources of variation found in batch ovens and coolers. The following sources of batch oven variation (Table 2) are reduced or eliminated by continuous systems:

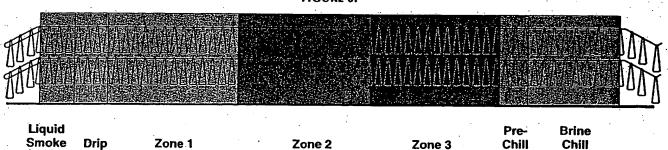
- Differences among multiple ovens of different designs, dimensions, and ages
- Differences among operators for different ovens over multiple shifts
- Differences in operator training and experience
  - For these first three bullets, continuous processing reduces variation because similar products all go through the same continuous oven, eliminating variation due to multiple ovens and operators.
- Inconsistent loading practices
- Fixed loading positions on continuous conveyers reduce variation by forcing proper and consistent product spacing.
- Variable lag times between cooking and cooling
  - In continuous systems, variable lag times are eliminated because products are chilled immediately after cooking.
- Oven maintenance
  - Maintenance is generally better for continuous systems than for batch equipment.
- Optimization of cooking processes
  - Continuous systems are generally designed around optimized processes.
  - Similar products all go through the same continuous process, creating consistent shrinks and quality characteristics.

Because continuous systems inherently reduce or eliminate many sources of variation that exist for batch ovens, product variation is generally much lower for continuous systems than for batch equipment.

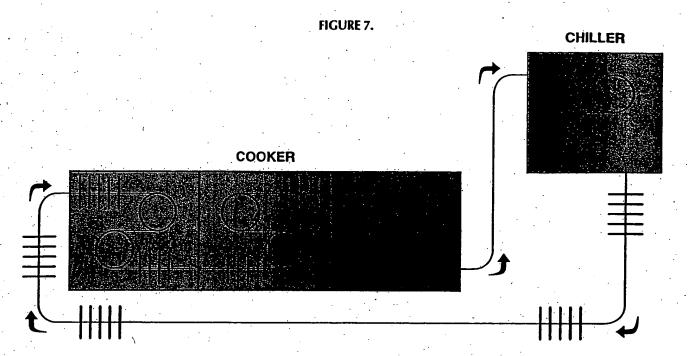
### **Reducing Variation by Eliminating Processes**

Reducing variation through process improvements is not the only way to reduce product variation. Another method is to eliminate steps within a process or even entire processes. In this way, the variation within a process or process step is not just reduced, it is completely eliminated. This method also simplifies the manufacturing process, making it more consistent and repeatable.

FIGURE 6.



Tunnel Continuous System.



Horizontal Serpentine Continuous System.

### **Eliminating Processes or Steps in a Process**

In evaluating opportunities for eliminating processes, we must ask the question, "Is the process necessary to satisfy a consumer preference, or is it just the way we have always done it?" In other words, do consumers actually want it, or is it just industry tradition?

One commonplace example of a process that was successfully eliminated many years ago is the smoking process for bologna. Although it was once a smoked product, most processors no longer smoke bologna, and consumers no longer expect it to be smoked. Eliminating this process simplified bologna manufacturing and eliminated any variation associated with uneven or inconsistent smoke color.

Another example of eliminating a process is the replacement of conventional smoking methods with pre-smoked fibrous casings. Using pre-smoked casings, the product absorbs liquid smoke from the casings instead of from an external application of traditional or liquid smoke. This method eliminates conventional smoking processes and any smoke color variation associated with those processes.

### **Microwave Bacon Processing**

Newer products such as microwave bacon may hold opportunities for changing or eliminating processes or process steps. Although microwave bacon is manufactured many different ways in the U.S., most processors follow some form of the following procedure:

### **U.S. Bacon Manufacturing Process**

- Inject bellies
  - Usually pump to 110–115% of green weight

- 2. Smoke and partially-cook bacon in smokehouse
  - Cook to 52–54°C core temperature
  - Shrink to 100-102% of green weight
- 3. Cool and temper
- 4. Press
- 5. Slice
- 6. Fully-cook slices in continuous microwave

American meat processors often specify a mahogany-red smoke color for bacon after cooking and smoking. If the bacon is to be sliced and microwave-cooked later in the manufacturing process, however, the surface color is less important. Strict adherence to a traditional mahogany-red smoke color is probably unnecessary for microwave bacon, and therefore the color specifications could be relaxed. To eliminate the smoking process altogether, liquid smoke could be injected into the product.

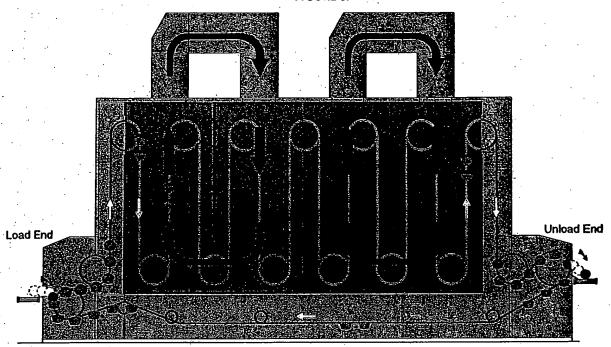
The following example is a microwave bacon production process used in the U.K. that eliminates conventional smoking:

### **U.K. Bacon Manufacturing Process**

- Inject bellies
  - Inject liquid smoke with brine
- 2. Steam cook
- 3. Cool/Temper
- 4. Press
- 5. Slice
- Fully-cook in continuous microwave

For the U.K. process, instead of conventionally smoking the bacon, liquid smoke is injected into the product. Elimi-

### FIGURE 8.



Vertical Serpentine Continuous System.

nating the smoking process simplifies the overall process and eliminates any smoke color variation. The bacon is steam cooked instead of ovencooked, thereby reducing shrink variation. Finally, because the new process is much shorter than a conventional one, it would be more readily converted from a batch to a continuous process. Continuous processing would further reduce product variation.

This U.K. bacon process is a useful example of reducing variation through process changes and improvements. Nevertheless, process changes for U.S. meat products must always be evaluated as to product conformance to USDA regulations and labeling standards. The effects of process changes on product quality must also be evaluated.

### ganid Simtangang Pragueiked Mensika dinak-

The conventional smoking processes commonly used for precooked products such as molded hams and turkey breast could be simplified to save time and reduce variation. For example, in a conventional process for smoked turkey breast, the deli-breast is steam cooked and then smoked using the following procedure:

### Conventional Smoking Procedure for Precooked Turkey Deli-Breast (3.5–4.0 kg)

- 1. Steam cook turkey breast in plastic film
- 2. Strip fully-cooked products out of plastic film and place
- 3. Load racks into batch ovens
- 4. Smoke using a traditional- or liquid-smoke process
  - Process time = 2-6 hours

- 5. Move racks from oven to air cooler.
- 6. Cool to less than 4°C core temperature
- 7. Package

This conventional smoking process is necessary to produce smoked turkey breast, but it also causes cooking and cooling shrink along with color and shrink variation.

Replacing this conventional batch process with a continuous rapid-smoking process would eliminate several process steps, reduce shrink and shrink variation, and improve color uniformity. The following rapid-smoking procedure has been used for precooked turkey breast:

### Raphi Smelingikanasinaani ikasemika Lurta Delilitens

Team cook turkey breast in plastic film
Tup fully-cooked products out of plastic film and load
onto continuous oven conveyer

- Shower product with liquid smoke at entrance to oven
- Dry product in oven for 10–15 minutes using highvelocity air at 65°C to develop smoke color
- Product automatically unloaded
   Eckage

ol to less that 4°C core temperature

The rapid-smoking process is shorter, simpler, and more consistent than a conventional process. The continuous process reduces the shrink and shrink variation inherent in batch processes. Color uniformity is improved because all prod-

uct is run through the same continuous oven instead of multiple batch ovens. Finally, packaging the product before cooling eliminates cooler shrink and shrink variation.

### **Key Points for Reducing Process Variation**

The key points for reducing process variation are summarized as follows:

- Eliminate processes and process steps where possible
   Consumer preferences, not industry tradition,
  - should guide the evaluation of process changes and improvements
- Replace existing processes with less variable ones
  - Use steam or hot-water cooking where possible
- Replace conventional smoking with new pocess innovations such as rapid- smoking or pre-smoked casings
- Optimize cooking, smoking, and cooling processes to reduce variation
- Train operators and production supervisors to understand the sources and cost of product variation, and how to reduce it
  - Uneven operator experience and training often cause load-to-load variation among ovens
- Conduct regular oven maintenance and calibration
  - Out-of-calibration control systems and irregular oven maintenance commonly cause product variation
- Evaluate new equipment options
  - Understand how oven and cooler designs can be used to reduce variation
  - Convert from pneumatic to electronic oven controls
- Convert from batch to continuous ovens wherever justifiable
- Consider cooling as part of the process
  - Rapidly cool products after cooking
  - Water shower products before moving into air coolers
  - Use non-shrink cooling methods such as brine chilling when possible

### Conclusion

Product variation is a huge cost to the meat industry. Reducing variation is therefore essential to achieve our common goal of manufacturing consistent-quality meat products at the lowest possible cost.

To reduce variation, we must first identify the sources of variation within manufacturing processes — in other words,

find the holes that need fixing. Process improvements and changes can then be evaluated and implemented. New manufacturing techniques can also be used to simplify processes and to eliminate some sources of variation altogether. In the end, reducing variation will enable us to drive down costs and make it easier to manufacture products right the first time and every time.

### Acknowledgments

My thanks to Dr. Ken McMillin and the American Meat Science Association for inviting me to speak at the Reciprocal Meat Conference. My thanks also to Alkar for their support in the preparation of this presentation and manuscript. The assistance and encouragement of Shannon Farrell, Peter Senn, and Paul Rapp are much appreciated. The guidance of Dr. Robert LaBudde is also much appreciated. Special thanks to Mike Lesiak of Campbell Soup Company for his valuable assistance — let the good times roll.

### References

- Bengtsson, N.E.; Jakobsson, B.; Dagerskog, M. 1976. Cooking of beef by oven roasting: A study of heat and mass transfer. J. Food Sci. 41: 1047-1053.
- Fellows, P. 1988. Food processing technology: Principles and practices. Ellis Horwood Ltd. Chichester, England.
- Godsalve, E.W.; Davis, E.A.; Gordon, J.; Davis, H.T. 1977. Water loss rates and temperature profiles of dry cooked bovine muscle. J. Food Sci. 42: 1038–1045.
- Hanson, R.E. 1988. Effects of cooking temperatures, relative humidity and energy level on heat and mass transfer in fine-cut sausages. M.S. Thesis, lowa State University, Ames, IA.
- Hanson, R.E. 1990. Cooking technology: Heat & moisture transfer in meat products. In: "Proceedings of the 43rd Reciprocal Meat Conference," National Livestock & Meat Board, Chicago, IL.
- Heldman, D.R. 1975. Heat transfer in meat. In: "Proceedings of the 28th Annual Reciprocal Meat Conference," National Livestock and Meat Board, Chicago, IL.
- LaBudde, R. 1989. Analysis of smokehouse variability on a variety of products and casing sizes. Least Cost Formulations, Ltd. Virginia Beach, VA.
   LaBudde, R. 1991. Process control the easy way. Least Cost Formulations, Ltd. Virginia Beach, VA.
- Skjöldebrand, C. 1980. Convection oven frying: Heat and mass transfer between air and product. J. Food Sci. 45: 1354–1362.
- Thompson, B.J. 1995. Typical sources of loss in the meat processing supply chain. Unpublished.

### **Biography**

Robert Hanson is Technical Development Manager at the Alkar Division of DEC International. He has been with Alkar for 11 years, and his work includes the development and research of cooking and chilling processes for batch and continuous cook/chill equipment. Bob has a bachelor's degree in Agricultural Engineering Technology and a master's degree in Meat Science. His master's research focused on heat and mass transfer in meat products during cooking.



### RADIANT WALL OVEN APPLICATIONS

The World's first patented, self-cleaning Radiant Wall Oven

- Natural browning of product surfaces in high temperature/short dwell for the best yield retention
- Develop smoke color through radiant energy in 1 minute or less on finished products and also set liquid smoke on raw products prior to thermal processing
- Surface sterilize products for pathogen reduction/elimination and for shelf life extension
- The Radiant Wall Oven is capable of flame roasting of vegetables and also of short dwell time processing for the peeling of many vegetables
- Technical Benefits of the Radiant Wall Oven and the Multipass Oven

Phone: 1-800-851-8516

1-978-851-8512

Fax: 1-978-851-4029

E-mail: Rdupre@nevent.com

HOME ABOUT RADIANT WHAT'S PRODUCT CUSTOMER INFORMATION PYRAMID WALLOVEN NEW INFORMATION SUPPORT REQUEST

|| <u>Home</u> || <u>About Pyramid</u> || Radiant Wall Oven Applications || || <u>What's New</u> || <u>Product</u>

Information || <u>Customer Support</u> || <u>Information Request</u> ||

© Copyright 1996, Pyramid Manufacturing.



- Company Information and Background
  - Patents
- Directions to Pyramid from Logan International Airport



### Company Information and Background

The Radiant Wall Oven was developed to address the problems that continually challenge the food processing industry. The most pertinent of these being the effective and safe cooking of red meats, whole mussels, pork patties and links, poultry in its whole and cut-up forms.

High speed conveyor ovens (convection, high velocity impingement, electric and gas inferred) were well designed to cook any given product. However a Radiant Wall Oven (RWO), with its ultra-high cooking temperatures, greatly increases production rates. By operating at a temperature between 1,000 and 1,500 degrees Fahrenheit, the RWO greatly reduces the time and chemicals normally associated with cleaning standard conveyor ovens.

In 1995, Bob Forney and Ernie Brown, who both hold patents in Food Processing Technology, approached the B.D. Air Systems Company, Inc. with their idea for the Radiant Wall Oven. By combining old-world craftsmanship with state of the art technology, B.D. Air Systems Company, Inc. has created one of the finest high speed ovens in the world. The RWO can brown, condition or assist in the application of Liquid Smoke.

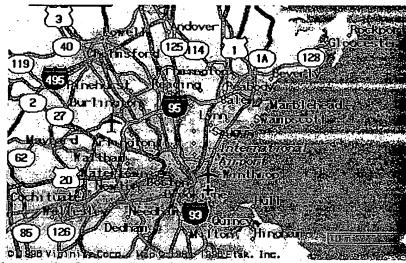
Allow our staff of Engineers and Food Scientists to test and gather information on your food processing requirements. Simply fill out an information request form, and we will be pleased to test your product.

### **Patents**

The Radiant Wall Oven has received a Patent from the U.S. Patent office.

### Directions to Pyramid from Logan International Airport

Pyramid Food Processing is approximately 1 hour (35 miles) from Logan International Airport.



Follow the airport loop to the Sumner Tunnel, go through the tolls and into the tunnel, look for a sign reading "Interstate 93 North". Follow these signs and get onto the highway heading North. Follow I-93N to exit 44 South. You will now be on Interstate 495 South. Get off of I-495 at exit 38. At the end of the ramp take a left. Follow this road approximately 1 mile, and take a left onto Capital Avenue. Approximately 200 yards on Capital Avenue take a left and follow this road, Pyramid Food Processing will be right in front of you.

Phone: 1-800-851-8516

1-978-851-8512

Fax: 1-978-851-4029

E-mail: Rdupre@nevent.com

HOME ABOUT RADIANT WHAT'S PRODUCT CUSTOMER INFORMATION PYRAMID WALL OVEN NEW INFORMATION SUPPORT REQUEST

|| Home || About Pyramid || Radiant Wall Oven Applications || || What's New || Product Information || Customer Support ||

Information Request ||

© Copyright 1996, Pyramid Manufacturing.



### RADIANT WALL OVEN APPLICATIONS

The World's first patented, self-cleaning Radiant Wall Oven

- Natural browning of product surfaces in high temperature/short dwell for the best yield retention
- Develop smoke color through radiant energy in 1 minute or less on finished products and also set liquid smoke on raw products prior to thermal processing

The Radiant Wall Oven is capable of flame roasting of vegetables and also of short dwell time processing for the peeling of many vegetables

Technical Benefits of the Radiant Wall Oven and the Multipass Oven

Phone: 1-800-851-8516

1-978-851-8512

Fax: 1-978-851-4029

E-mail: Rdupre@nevent.com

HOME ABOUT RADIANT WHAT'S PRODUCT CUSTOMER INFORMATION PYRAMID WALL OVEN NEW INFORMATION SUPPORT REQUEST

|| Home || About Pyramid || Radiant Wall Oven Applications || || What's New || Product Information || Customer Support || Information Request ||

© Copyright 1996, Pyramid Manufacturing.



### PRODUCT INFORMATION

### General Information

- Pyramid Radiant Wall Oven
- Pyramid Multipass Oven
- Radiant Wall Oven Tonnage Capabilities
- \* RWO treament of Marinated Chicken Breasts

### Pyramid Radiant Wall Oven

The Radiant Wall Oven is available in three conveyor widths, all have 90" of cooking length.

Pretreatment stations as well as inline cooking ovens are easily adapted to fit the Pyramid Radiant Wall

Oven. In most cases the RWO can greatly reduce the amount of floor space normally required by standard production oven lines.

Pyramid Food Processing offers three standard unit sizes:

20/90 - 20" wide belt and 90" long effective radiant zone 30/90 - 30" wide belt belt and 90" long effective radiant zone 40/90 - 40" wide belt belt and 90" long effective radiant zone

Oven length can be extended by combining units to meet and production line speed requirements.

### **RWO treatment of Marinated Chicken Breasts**

Samples	Da	ıy 0	Day 7		Day 14		Day 21		Day 23
	First exp.	likepeat	First exp.	Repeat	First exp.	Repeat	First exp	Repeat	Repeat
Α	2.1 X 10 <sup>4</sup>	1.8 X 10 <sup>4</sup>	9.0 X 10 <sup>3</sup>	4.5 X 10 <sup>4</sup>	3.5 X 10 <sup>6</sup>	2.1 X <sub>1</sub>		1.7 X 10 <sup>7</sup>	•
В	3.3 X 10 <sup>4</sup>	N . 1	5.5 X 10 <sup>3</sup>	3.9 X 10 <sup>4</sup>	2.0 X 10 <sup>6</sup>		1	2.0 X 10 <sup>7</sup>	-
С	1.1 X 10 <sup>2</sup>	2.1 X 10 <sup>2</sup>	1.4 X 10 <sup>3</sup>	1.3 X 10 <sup>3</sup>	5.9 X 10 <sup>5</sup>	U _ I	2.3 X 10 <sup>7</sup>	4.1 X 10 <sup>6</sup>	3.9 X 10 <sup>7</sup>
11173		1 1		2.0 X 10 <sup>3</sup>		I			2.0 X 10 <sup>7</sup>
control		l t	l l	_ [		3.1 X 10 <sup>7</sup>	_		-

Numbers in bold denotes "spoiled"

- A Marinated without Ional (No RWO)
- B Marinated with Ional (No RWO)
- C Marinated without Ional (RWO treated)
- D- Marinated with Ional (RWO treated)

Phone: 1-800-851-8516

1-978-851-8512

Fax: 1-978-851-4029

E-mail: Rdupre@nevent.com

HOME ABOUT RADIANT WHAT'S PRODUCT CUSTOMER INFORMATION PYRAMID WALL OVEN NEW INFORMATION SUPPORT REQUEST

|| Home || About Pyramid || Radiant Wall Oven Applications || || What's New || Product Information || Customer Support ||

Information Request ||

© Copyright 1996, Pyramid Manufacturing.

### SHELF LIFE EXTENSION AND PATHOGEN REDUCTION OF FRESH CHICKEN THROUGH SURFACE PASTEURIZATION USING RADIANT HEAT AND ANTI-MICROBIAL AGENTS

By

### MD. MAHBUBUL ISLAM

For. B. Astrakhan Technical Institute for Fisheries, USSR, 1981

M.S., University of Rhode Island, 1993

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

UMI Number: 9920046

The property of the contract o

Carlos Caras of Soft and Soft sold the control of the control

all of granters are described to the contract of the second

1988年,**建筑**的大学,在中国大学的大学的大学,但是一个大学的大学的大学的大学的大学的大学的

UMI Microform 9920046
Copyright 1999, by UMI Company. All rights reserved.

Commence of the Commence of th

This microform edition is protected against unauthorized copying under Title 17, United States Code.

JOM 300 North Zeeb Road Ann Arbor, MI 48103 This is an authorized facsimile, made from the microfilm master copy of the original dissertation or master thesis published by UMI.

The bibliographic information for this thesis is contained in UMI's Dissertation Abstracts database, the only central source for accessing almost every doctoral dissertation accepted in North America since 1861.





300 North Zeeb Road P.O. Box 1346 Ann Arbor, Michigan 48106-1346 USA

800.521.0600 734.761.4700 web www.il.proquest.com

Printed in 2003 by digital xerographic process on acid-free paper

DPG\*

### **INFORMATION TO USERS**

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.



### SHELF LIFE EXTENSION AND PATHOGEN REDUCTION OF FRESH CHICKEN THROUGH SURFACE PASTEURIZATION USING RADIANT HEAT AND ANTI-MICROBIAL AGENTS

and the same of the same the same as well

By

MD. MAHBUBUL ISLAM

Approved:

Major Professor

Kores Isled

12-8-98

The contract the same state of the contract of

Gordhan L. Patel

and fight and state for comparing the control of the

Dean of the Graduate School

12a-20 11, 198

Date

### MD. MAHBUBUL ISLAM

and Markette

Shelf life extension and pathogen reduction of fresh chicken through surface pasteurization using radiant heat and anti-microbial agents. (Under the direction of ROMEO TOLEDO)

As of the first the second

Whole broilers exposed to a radiant wall (RW) at 649°C, for 0, 3, 4, 5, or 8 s or dipped in a solution containing 1% buffered sodium citrate, pH 5.8 (BSC), 0.5% citric acid (CA) or 2% liquid smoke (LS) prior to RW exposure. 5 s exposure reduced total plate count (TPC) 1.23 to 1.73 log without any noticeable change in organoleptic properties. Dipping in 1% BSC was synergistic with RW in reducing the TPC but CA and LS pre-treatments had no effect. TPC inside body cavity was not affected by radiant heat.

TPC of raw chicken drumsticks, dipped in BSC (6%) and exposed 3 s to a radiant wall (RW) at 788°C was reduced by 2 to 3 log, providing a shelf life of 27 d at 0°C vs. 13 d for controls and 18 d for RW treatment only. At 4°C, shelf life of BSC/RW treated drumsticks was 21 d vs. 10 d for control and 13 d for RW only treatment. Skin modification by different scald procedures affected shelf life of RW treated drumsticks: semi-scald (52°C) shelf life at 0°C was 29 d vs. 23 d for sub-scald (60°C) for similarly treated drumsticks.

No viable CFU of Salmonella typhimurium or Campylobacter jejuni were detected on raw chicken drumsticks inoculated with 1,000 CFU and exposed 3 s to RW at 788°C. There was no recovery from heat injury after 3 d refrigerated storage at 4°C. Challenge studies with large inoculum of each pathogen gave log reductions of 0.79, 1.73 and 2.32 for S. typhimurium on fresh chicken drumsticks treated respectively with only BSC, only RW and combined BSC/RW. Similar

treatments on *Campylobacter jejuni* yielded 1.45, 2.41, and 3.36 log reduction respectively.

INDEX WORDS: Pasteurization, Radiant heat, Poultry, Chicken, Antimicrobials,

Sodium Citrate, Shelf life, Microorganisms, Pathogen,

Salmonella, Campylobacter

1. 1. 2. 4. 5. 1. 1. 1. 1. 1.

and the second of the second o

AND SEE HE CONTRACTOR OF THE PROPERTY OF THE P

1949 BV

and a tribulation, who is a respect to belong the Committee of the Committee of property of the committee of p

internation of the first for the extremental extremental extremental description of the extremental ex

and the state of the control of the state of the control of the co

ja kej apravanskas <mark>itiga</mark>rentara metalagari albanakarikan lakifetara lahiti. Hali sebagai kera

The Market was the Color of the second of

等收入1000年出版的1800年的1812年的1818年的

THE RESIDENCE OF SHEET WHICH THE REPORT OF THE PROPERTY OF THE PARTY OF THE PROPERTY OF THE PARTY OF THE PARTY.

e desenta a la como de la compaño de la c

### ACKNOWLEDGMENTS

was in the control of the control of

T. Toledo, for his patience and guidance during the course of this work. Without his help and encouragement this goal may not have been reached. I would also like to thank the members of my dissertation committee, Dr. Daniel L. Fletcher, Dr. Aaron Estes Reynolds, Jr., Dr. Yao-Wen Huang, and Dr. Mark A. Harrison, for their valuable time and help when needed.

I would also like to thank the faculty, staff, and all the students of the Department of Food Science and Technology for their valuable support, encouragement, ideas and friendship and who have made my stay here enjoyable.

I am highly appreciative of love and sacrifice demonstrated by my wife, Ruby, and my three wonderful children, Farah, Ridwan, and Imran. They were my only strength during these long years of my life.

Finally, I express my countless thanks to my father, who put his confidence in my capabilities and patiently waiting for this day to happen. He will be very proud and happy, as would have been my mother, who passed away during my MS program and my father-in-law, who passed away in the midst of my dissertation work. I dedicate this dissertation to their loving memory.

### TABLE OF CONTENTS

· 建设。 医腺体管 ())	tar on our or to be a con-	1 - 41 -	as no defeate		Pag
Acknowledg	ments				ii
<u>Chapters</u>		g <sup>en</sup> er i jak			
Chapter 1 :	Introduction		Descriptions		
Chapter 2:	Literature Review	<b>/</b>			
	Inactivation of mid				by radiant
	heat and antimic		artiglik gjallig Nor		Y AND ST
Chanter 4:				narte hy rad	
	energy on microb				70
	Destruction of Sa		·		
	Campylobacter je, treatment in a rad	iant wall ov	en		98
EPARA ANA EPARAN L				ATT A MARKET	
	Conclusion			4. 作品或 。	119
				entrolli.	
• •	Infrared temperatu				
eval see a f	drumsticks treated	l in a radia	nt wall oven		137

 $\mathcal{F}[N] \otimes [G]$ 

(1965) The

# CHAPTER 1 INTRODUCTION

Poultry is one of the most widely accepted muscle foods in the world and is preferred by health conscious consumers as a low-fat alternative to beef. Over the last 50 years, poultry-meat production has undergone considerable expansion in much of the developed world. The industry has changed from an essentially family farm-based operation to one where economies of scale in rearing and processing have led to a high degree of operational efficiency. Processing, in particular, has become more mechanized, so that most stages in production of oven-ready whole broilers or cut portions are now either semi- or fully-automated, thus reducing labor costs and helping to maximize the speed and efficiency of the process. However, not all of the changes that have taken place have necessarily been in the best interests of maintaining product quality, e.g., in relation to meat tenderness and microbial contamination. Although poultry meat is rightly regarded as a wholesome, nutritious and cheap form of dietary protein, it is not without some problems. From the moment the bird is killed, the meat can support bacterial growth, which results in the production of off odors and discoloration.

Fresh poultry is extremely perishable. So, maintenance of shelf life is of primary importance. The shelf life of fresh poultry depends on the number of spoilage bacteria on the product immediately after processing and the holding temperature of the product during transportation, distribution and storage. Spoilage occurs when certain species of psychrotrophic bacteria multiply on

surface of chicken held at refrigeration temperatures and produce metabolic byproducts that change the appearance, pH, or odor of the product.

Poultry transmitted diseases are major burdens on society causing considerable suffering and loss of productivity, and add to the cost of food production and health care. Among the diseases that can be acquired by ingesting undercooked or re-contaminated poultry or handling raw poultry, salmonellosis and campylobacteriosis are of primary concern in the United States. Risks of acquiring these diseases are greatly influenced by the prevalence of Salmonella species and Campylobacter jejuni in live birds and subsequently on poultry products. The origin of this problem lies with the large scale operations used in rearing and the processing the birds. Under such conditions, the transmission of a minority of the total resident microorganisms, e.g., Salmonella, occurs readily and cannot be easily prevented. Elimination of these gram-negative food-borne pathogens at the production level is currently not feasible. Therefore, an intervention step to substantially reduce or eliminate them during processing is desperately needed to ensure the safety of raw poultry product. Methods, which efficiently reduce microbial numbers, would afford the added benefit of extending the relatively short shelf life of fresh poultry.

Efforts to eliminate or substantially decrease bacterial population on poultry have been made by the poultry industry. With the exception of food irradiation, which has a high initial capital expense, few, if any processing technologies currently exist that significantly reduce or eliminate the microbiological hazards on the surface of raw poultry. Very rapid surface heating for a short time is thought to be an effective method in reducing the number of microorganisms on the surface. The original premise was that less heat would be

needed to kill organisms on a surface, than to cook that surface, due to the much higher activation energy of cooking, as compared to killing. Hence killing without cooking would depend on the rapidity of heating. To achieve this, we used a n w type of oven, Radiant Wall Oven (RWO) (Fig. 1), in which whole chicken broilers/ chicken drumsticks were subjected to a very high temperature for a very short period. The surface of the chicken was heated by radiant heat in an attempt to kill the microorganisms on the surface without inducing noticeable organoleptic changes. Antimicrobial agents may also act synergistically with the radiant heat.

The objectives of the study were: to optimize time and temperature for radiant heat treatment of chicken, to extend the shelf life of chicken by reducing initial microbial counts by application of radiant heat and in combination with GRAS antimicrobial agents at different storage temperatures, to determine the efficacy of these combination treatments on Salmonella typhimurium and Campylobacter jejuni on fresh chicken and to measure the actual surface temperature of chicken due to the action of radiant heat on its microbial population.

。1965年,1964年,1967年,1967年,1966年,1966年,1967年,1968年,1968年,1968年,1968年,1968年,1968年,1968年,1968年,1968年,1968年,1968年,1

where the lay this space will also be regular a college, but a factorized a given some and the

granding that the court terms of a transmit ground by the court of the

was interpretation the processor of the consideration of the page of page 100 and processor before

Before a secretario for mane in process of the contraction of the cont

n nghi kujung ang kangangan kanggalan ng Pingurung na ang mga ng Anggang ang kanggang kanggan kanggan kanggan

aka Tipita kan tahuka tagan kendada di tagan tagan di digan di di angan angan dalah dalah tagan dan Kita.

ng the Marketing ang bully nampe to be a name of the control of the control of the control of the activities of

Company that the age of the most consequence with his properties of the

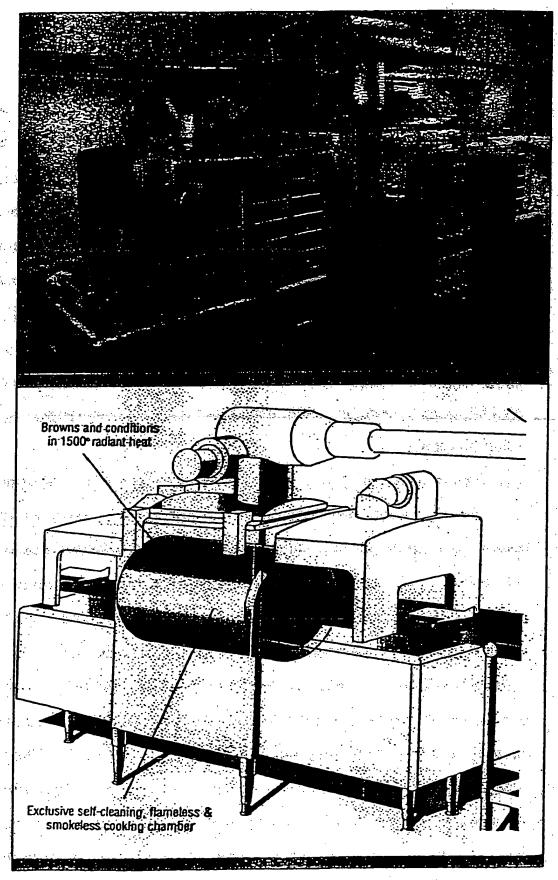


Fig. 1: Radiant Wall Oven (picture and schematic)

#### CHAPTER 2

# REVIEW OF THE LIFERATURE

## 2.1. IMPORTANCE OF POULTRY PROCESSING INDUSTRY

Over the last few years there has been an increasing output of poultry meat and poultry meat products (USDA, 1998). Both national and international trade in poultry meat have increased (Simonsen; 1989). Twenty-four billion pounds of broiler chicken meat were processed in the United States in 1994 and approximately 80 % of this meat was sold fresh (Russell, 1997). Per capita consumption data for chicken in the USA are shown in Table 1 covering 1989 to 1998. During this period per capita consumption of chicken meat has increased from 68 to 88 pounds. In 1998, estimated production of chicken is more than 29 billion pounds.

## 2.2. TYPES OF MICROORGANISMS ASSOCIATED WITH FRESH CHICKEN

Poultry meats are derived from warm-blooded animals. Their microbial flora is heterogeneous, consisting of mesophilic and psychrotrophic bacteria from the animal itself, soil and water bacteria from the environment, and bacterial species introduced by man and equipment during processing (Grau, 1986; ICMSF, 1980). The widespread sale and use of raw chicken demands closer attention to their microbiology. Chilled or frozen, chicken may be marketed as whole, whole cut-up, bone-in parts or deboned. With few exceptions, bacterial growth is a surface phenomenon in raw poultry products. The quality of the chicken meat is considered optimum immediately after processing, and maintenance of acceptable quality depends on initial microbial levels and measures taken to minimize the growth of organisms. The two major concerns

are control of spoilage organisms which cause consumers to reject the product due to unacceptable odor or flavor, and minimization of pathogenic organisms which may, under prolonged storage or faulty handling, lead to a health hazard (Cunningham, 1987).

TABLE 1: PRODUCTION AND PER CAPITA CONSUMPTION, READY-TO-

	Production			Consumption	
Year	Commercial broilers (Million pounds)	Other Chickens (Million pounds)	Total¹ (Million pounds)	Total <sup>3</sup> (Million pounds)	Per capita (Pounds)
1989	17,22 <b>7</b>	531	17,758	16,88 <b>6</b>	68
1990	18,430	523	18,953	17,762	71
1991	19,591	508	20 <b>,</b> 09 <b>9</b>	18,751	-74
1992	20,904	520	21,424	19,826	78
1993	22,015	515	22,530	20,520	79
1994	23,66 <b>6</b>	509	24,175	21,103	81
1995	24,827	496	25,323	21,238	81
1996	26,124	491	26,615	21,854	82
1997 <sup>2</sup>	27,061	509	27,570	22,509	84
1998 <sup>4</sup>	28,556	530	29,086	23,876	88

Totals may not add due to rounding

Forecast

(Source: USDA, Agricultural Statistics, 1998, page VIII-37)

The chief microbiological concerns associated with fresh chicken center around two types of microorganisms - psychrotrophs that grow during extended refrigerated storage and mesophiles, which grow in the product subjected to

<sup>&</sup>lt;sup>2</sup> Preliminary

<sup>&</sup>lt;sup>3</sup> Shipments to territories included

temperature abus. Psycrotrophs are bacteria, yeast, and molds that grow, although slowly, at refrigeration temperatures (below 7°C) but grow optimally at temperatures above refrigeration, e.g., 25°-30°C (Marth, 1998). Their maximum growth temperatures are 30°-35°C (Kraft, 1992; Olson and Nottingham, 1980). Mesophilic microorganisms could survive under refrigerated storage and grow when food is temperature-abused. Mesophiles grow well between 20°-45° C with optimum growth between 30°-40° C (Jay, 1992). The potential for psychrotrophic spoilage microorganisms to grow during the extended refrigerated storage period and decrease organoleptic quality or spoil the food product is a concern. Additionally, psychrotrophic and mesophilic pathogens are also present on poultry.

The surface flora on freshly slaughtered carcasses, usually about 10<sup>2</sup> to 10<sup>4</sup> bacteria per square inch, is primarily mesophilic, having originated from the alimentary tract and external surfaces of the live animal. Contamination from the slaughtering environment is also largely mesophilic in nature since this process occurs in rooms ambient in the summer and heated in the winter (Barnes, 1976). Psychrotrophic organisms originating from soil and water are present but usually only to about 10<sup>1</sup> per square inch (Surkiewicz et al., 1969). The mesophiles are important because they indicate the effectiveness of sanitation practices in the processing plant. Populations of bacteria on surfaces of raw poultry carcasses at the end of processing vary, but typically the range is from 10<sup>3</sup> to 10<sup>5</sup> aerobic mesophillic organisms per inch<sup>2</sup> (ICMSF, 1980). Because the post-processing environment is frequently refrigerated, a low-level recontamination with psychrotrophic bacteria almost always occurs. The psychrotrophs are important because they increase in numbers even though the products are stored at proper

refrigeration temperatures. They ultimately cause spoilage and thus determine the shelf life of the product. When chicken is held under refrigeration, the micro flora begins to shift toward psychrotrophs of the *Pseudomonas-Acinetobacter-Moraxella* group (Barnes, 1976). Earlier studies by Barnes and Impey (1969) found that the organisms most commonly found growing on poultry carcasses at low temperatures (around 1°C) were pigmented and non-pigmented species of *Pseudomonas, Pseudomonas putrifaciens*, and strains of *Acinetobacter*. These authors also noted that *P. putrifaciens* grew much faster on leg muscle than on breast, and explained this on the basis of a difference in pH - leg muscle having pH 6.4 - 6.7, and breast 5.7 - 5.9. In an earlier report (Ayres 1959), it was stated that the microbial population responsible for spoilage of the refrigerated product (4°C) was psychrotrophic. After 12 days storage, the dominant psychrotrophic population was 90% *Pseudomonas-Achromobacter*. Pseudomonads were the most significant Gram negative rods associated with spoilage of poultry.

## 2.3. IMPORTANT PATHOGENIC MICROORGANISMS IN CHICKEN

Although efforts are being made to reduce this contamination, none of the currently available procedures can provide pathogen-free raw poultry. Campylobacter, Staphylococcus aureus, Listeria monocytogenes, and Salmonella are often present on fresh poultry because the steps involved in the slaughtering process are inadequate to eliminate these organisms. Although the recently mandated Hazard Analysis Critical Control Points (HACCP) procedures have reduced the incidence of pathogens in fresh poultry, there are still a substantial percentage of the product which harbor the pathogens. The level of coliforms has been commonly used as an indicator of hygienic conditions in the

handling of fresh poultry and the microbiological quality of meat and poultry products. However, since multiplication of certain psychrotrophic coliforms will occur during refrigerated storage, the coliform results lose their significance as an indicator of the hygienic conditions during production when sampling is done at a later stage in storage. This is also one, among several, reasons why coliform values are not an effective indicator of the safety of refrigerated poultry products. Although several bacterial pathogens have been associated with poultry-born human illnesses. Salmonella and Campylobacter jejuni are of primary contemporary concern. These are major human pathogens and poultry and poultry products are frequent vehicles of these bacteria (Bryan and Doyle, 1994). Public health officials estimate that Campylobacter isolates are responsible for 1.1 million to 7 million food borne infections and 110 to 1000 deaths per year. By comparison, food borne Salmonella sickens some 700,000 to 4 million peopl, though deadlier than campylobacters, killing up to 2000 per year (Anon. 1998). Costs associated with human salmonellosis in the United States have been estimated to be from 1-2.3 billion dollars annually and that for campylobacteriosis have been estimated to be between less than a million to 1.4 billion dollars annually (Bryan and Doyle, 1994). USDA estimates that approximately 40% of all raw poultry is contaminated with Salmonella (Sugarman, 1992). Although the reported occurence of C. jejuni in poultry ranges from 0 to 100%, the median is 62% positive (Bryan and Doyle, 1994). The presence of these bacteria in poultry products could lead to human illnesses, deaths and associated costs to the poultry industry and consumers of poultry products.

i destino e de la compaña de la final en la desenvación de la compaña de la final de la final de la final de la

and the care and a compared to the compared of the figure absorbance of a figure of the absorbance of the figure

 $\mathbb{C} : \mathbb{R}^{n_1}$ 

## 2.4.1. Campylobacter spp.

Campylobacter was recognized as an animal pathogen long before it was identified as human pathogen responsible for gastroenteritis (Franco and Williams, 1994). Before 1972, when methods were developed for its isolation from feces, it was believed to be primarily an animal pathogen causing abortion and enteritis in sheep and cattle. Their importance as a cause of human diarrhea has been recognized only relatively recently and was quickly elucidated that many outbreaks of Campylobacter enteritis had a food origin. Campylobacter jejuni was responsible for most such outbreaks (CDC, 1988).

Campylobacters are Gram-negative, highly motile, small, spiral-shaped They are microaerophillic organisms, which means they have a requirement for reduced levels of oxygen. They are relatively fragile, and sensitive to environmental stresses (e.g., 21% oxygen, drying, heating, disinfectants, acidic conditions). The genus has been reviewed by Penner (1988). Campylobacteriosis is the name of the illness caused by C. jejuni. It is also often known as Campylobacter enteritis or gastroenteritis. The most common clinical symptoms of intestinal infection with C. jejuni are abdominal pain, fever and diarrhea, sometimes accompanied by vomiting. Pain and fev may precede diarrhea. Diarrhea may be profuse, watery and frequent or alternatively bloody. In the dysentery-like syndrome, fresh blood, mucus and leucocytes are found in the stool (Walker et al., 1986). Although diarrhea may be severe, dehydration is usually only a problem in the young or elderly. The illness usually occurs 2-5 days after ingestion of the contaminated food or water. Illness generally lasts 7-10 days, but relapses are not uncommon (about 25% of cases). Most infections are self-limiting and are not treated with antibiotics. However,

treatment with erythromycin does reduce the length of time that infected individuals shed the bacteria in their feces. The organism may be excreted in the feces for several weeks. Bacteraemia is rare. Illness is caused by infection of the intestinal tract. Illness has been caused by the ingestion of as few as 500-800 cells in milk (Robinson, 1981; Black et al., 1983). The mechanisms by which C. jejuni or C. coli cause diarrhea are suggested by the clinical symptoms. Secretory or watery diarrhoea may be caused by organisms adhering to the mucosa in the proximal small intestine and forming an enterotoxin (McCardell et al., 1984, 1986). Over 70% of C. jejuni strains also produce a cytotoxin (Johnson and Lior, 1986; Walker et al., 1986). Cytotoxin could be important in bloody diarrhea. Recent studies suggest that Campylobacter infection may be linked to Guillain-Barre Syndrome, Reiter's Syndrome and other forms of neuromuscular paralysis (Smith, 1995).

Since foods may contain only a few cells, liquid enrichment methods are normally required before selective plating in order to detect contamination with *C. jejuni*. Successful detection of these organisms requires incubation at 42°C under microaerobic conditions (5% oxygen and 10% carbon dioxide). For isolating *C. jejuni* from chicken carcasses, a blood-free charcoal-based agar (CCD blood-free agar) appears to be at least as selective as blood-containing selective agars in restricting the growth of contaminants while allowing good growth of *Campylobacter* colonies (Bolton *et al.*, 1986). *Campylobacter* colonies are non-hemolytic and may be flat, spreading and with an irregular edge or discrete, circular-convex and 1-2 mm in diameter. Suspect colonies are examined microscopically for the characteristic morphology and darting motility of

the antique of James and the same of the company of the first action of the company of

campylobacters. Campylobacters in food can be enumerated either by an MPN technique or by direct plating.

The intestinal tract can harbor C. jejuni and C. coli with no evidence of illness in a wide variety of wild and domestic warm-blooded animals (Franco, 1989; Skirrow, 1991). Campylobacters may infect man after direct contact with animals or indirectly via contaminated water, milk or meat. Since C. jejuni is regularly found on retail raw poultry, poultry is the largest potential source of Campylobacter for humans (Blaser et al., 1984). The consumption of rare or under-cooked poultry has been implicated in a number of small outbreaks (Skirrow, 1982; Blaser et al., 1984; Istre et al., 1984; Rosenfield et al., 1985). Sporadic cases of Campylobacter enteritis vastly outnumber the cases seen in outbreaks and poultry is believed to be responsible for many of the sporadic cases (Stern, 1992; Kaijser, 1988). Harris et al. (1986) estimated 48% of campylobacteriosis cases were due to consumption of contaminated chicken. It has been proposed that human infection is more likely from chilled than from frozen chicken because of the higher numbers of campylobacters surviving on the former (Hood *et al.,* 1988). At retail outlets, campylobacters are present in higher numbers on chilled-fresh than on frozen chicken (Gill and Harris, 1984; Hood et al., 1988). Campylobacters can be isolated from freshly slaughtered redmeat carcasses, but in smaller numbers than on poultry (Doyle, 1984).

Campylobacter jejuni is relatively sensitive to the lethal effects of heat,

D<sub>55</sub> values ranging from 0.6 to 2.3 min (Roberts, et al., 1996). The heating
milieu appears to have only a small influence on heat sensitivity, except that cells
heated in 0.1 M phosphate buffer (pH 7.0) exhibit a significantly faster loss of
viability compared with cells heated in peptone solutions or in foods (Gill and

Harris, 1984). Maximum heat resistance occurs at near pH 7.0, and decreases as pH moves away from neutrality. z-values range from 4.5 to 8.0 for temperatures between 48 and 60°C (Roberts, et al., 1996). Campylobacters are readily destroyed by pasteurization. Pasteurization is a critical control point in preventing human infection. *C. jejuni* is at least as sensitive as *E. coli* to chlorine and chloramine (Wang et al, 1983; Blaser et al., 1986). Proper chlorination of drinking water and maintenance of distribution systems are critical control points in preventing infection by waterborne campylobacters.

There are two ways in which *C. jejuni* on raw meats can remain present on foods ready for consumption: the meats may be eaten raw or undercooked, or, probably more importantly, campylobacters may be transferred from raw meat to ready-to-eat foods. *C. jejuni* is readily destroyed by cooking at temperatures of 55-60°C for several minutes. Control also requires precautions to avoid cross-contamination when preparing meals. Handling raw poultry or offal meats can lead to the contamination of hands, surfaces and other foods. Blood and chicken thaw-liquor have protective actions and markedly increase the survival time of camplylobacters (Coates *et al.*, 1987). Cooked meats and other foods can be recontaminated if placed on plates or surfaces that have held raw meats. Washing and drying hands removes even heavy inocula of *C. jejuni*. However, kitchen staff often merely rinse their hands without thorough drying (Coates *et al.*, 1987). Auto-infection may take place directly by the hand-to-mouth route during food preparation.

Campylobacter jejuni has moved from relative obscurity in the 1970s to a prominent position as a foodborne diarrheic pathogen in the 1990s and is the most common bacterial cause of enteritis in the United States (Tauxe, 1992).

However, it can not be dismissed as only a cause of a temporary, inconvenient gastrointestinal infection. It is now realized that *C. jejuni* is a cause of severe neuromuscular paralysis. Most of the burden to the public from infection by *C. jejuni* is economic: the cost of gastrointestinal illness induced by the organism is enormous and if that cost is coupled with the presently unknown costs of *C. jejuni* complications, the economic liability is unacceptably high (Smith, 1995).

#### 2.4.2. Salmonella spp.

A major health concern in poultry is the well-known association of pathogenic microorganisms of the Salmonella group with the poultry production environment. Poultry is still considered to be the single most important source of salmonellae (Cunningham, 1987). In most cases, careless handling of foods before consumption has been primarily responsible for the food borne illness like salmonellosis. Salmonella is not a heat-resistant organism and properly handled and/or cooked poultry constitutes no health hazard. Cross contamination to other food that are not cooked are the main concern.

Salmonella was recognized as a food borne pathogen before this century and has become recognised as a major cause of enteritis throughout the world (Bryan and Doyle, 1994). Budd (1874) was first to infer that typhoid fever was transmitted by water and food. Salmonella typhi, the etiological agent of the disease, was discovered in 1880 by Eberth and isolated in 1884 by Gaffky. S. cholerae-suis (the type species) was isolated from swine clinically diagnosed having hog cholera (Salmon and Smith, 1885). The genus name was coined by Lignieres in 1900 in honour of Dr Salmon's work. The first laboratory-confirmed outbreak of food borne salmonellosis involved 57 persons who ate meat from a sick cow. S. enteritidis was isolated from the organs of a victim who had not

survived and from the meat and blood of the animal. Since then, salmonellae have become recognized as a major cause of enteric fever and gastroenteritis.

Salmonella is a genus of the family Enterobacteriaceae (Brenner, 1984). Members of the family are characterized as Gram-negative, facultatively anaerobic, non-spore-forming, rod shaped bacteria. Motile forms have peritrichous flagella. Most members of this family are found in the intestinal tract of man and other animals as either pathogens or commensals. Approximately 2200 serovars of Salmonella have been identified (Brenner, 1984; Ewing, 1986). Different serotypes dominate in different parts of the world, but it seems that S. typhimurium is the type most frequently encountered. Other important species include S. enteritidis, S. heidelberg, S. agona, S. newport, S. infantis, S. panama, S. saint paul and S. welteveden.

Salmonellosis remains one of the three most common food borne diseases, and poultry and poultry products are the major source of salmonellosis in man (Silliker, 1982; Bryan, 1980 and 1981; Todd, 1980). The annual estimate of cases is 160,000 for Canada and 1,300,000 for the U.S.A. with medical costs in the U.S.A. exceeding \$1.2 billion (Bryan and Doyle, 1994). Major syndromes of salmonellosis are enterocolitis or gastroenteritis, enteric fever, bacteremia and fecal infection of various organs that may follow bacterimia. Common signs and symptoms of gastroenteritis are diarrhea, nausea, abdominal pain, mild fever and chills. The incubation period ranges from 5 h to 5 days, but signs and symptoms usually begin 12-36 h after ingestion of a contaminated food. The syndrom usually lasts 2-5 days. For enteric fever, the incubation period ranges from 7 to 28 days. Malaise, headache, high persistent fever, abdominal pain, body aches and weakness occur, commonly with either pea-like diarrhea or constipation.

Nausea, vomiting, cough, perspiration, chills and anorexia may occur. Rose spots sometimes appear on the trunk, back and chest. A slow heart rat, a tender and distended abdomen, enlarged spleen, and sometimes bleeding from the bowel or nose are observed. The senses are dulled and patients may become delinious. Relapses sometimes occur. Convalescence is slow (1-8 weeks). Bacteraemia or septicaemia is caused by the presence of salmonellae in the blood. The result is a high, persistent fever, pain in the back, abdomen and chest, chills, perspiration, malaise, anorexia and weight loss. The condition may be transient or chronic. Strains of *S. typhimurium*, *S. cholerae-suis* and *S. dublin* are liable to invade the bloodstream and fecal infections of various tissues may follow. Although uncommon, identified sequelae include: appendicitis, arthritis, cholecystitis, endozditis, local abscesses, meningitis, osteomyelitis, osteoarthritis, pericarditis, peritonitis, pleum, pneumonia and urinary tract infection (Archer and Young, 1988; Smith et al., 1993).

Early studies in human volunteers indicated that the ingestion of more than 10<sup>5</sup> salmonellae was typically required to cause illness in previously healthy adults (McCullough and Eisele, 1951). In some instances, however, particularly when the vehicle has been either water or fatty or buffered foods, small numbers (e.g.< 100/g) of salmonellae have been found in the epidemiologically implicated foods. (D'Aoust and Pivnick, 1976; Blaser and Newman, 1982).

Routine detection of salmonellae involves a sequence of pre-enrichment, enrichment, selective differential plating, isolation and identification. Incubation times are usually 16-24 h. Normally, incubation temperatures range from 35 to 43°C, although incubation at 41-43°C often results in increased detection of salmonellae. Commonly used selective broths include tetrathionate with brilliant

green and selenite with cystine. The presence of salmonellae is determined by plating samples of enrichment broths on selective plating media. Commonly used selective plating media include brilliant green, bismuth sulphite, Hektoen enteric agar, MacConkey, deoxyeholate citrate and Salmonella-Shigella agars. Salmonellae are enumerated by the most probable number technique (ICMSF, 1978; Speck, 1984) and direct plating.

Salmonellae are found worldwide and are universally recognized as zoonotic agents. Salmonellae reside in the intestinal tract of infected animals (including human beings). Foods of animal origin become contaminated following fecal contamination of the environment and equipment. Cross-contamination is produced by contaminated raw foods during further processing and preparation. Salmonella can also become established and multiply in the environment and equipment of a variety of food-processing facilities. Turkey and chicken meats are frequently identified as vehicles in outbreaks of salmonellosis. Poultry carcasses and parts are frequently contaminated with salmonellae, which reach carcasses from the intestinal tract or from fecal material on feet and feathers. Cross-contamination is a particular problem, and critical steps includ defeathering, evisceration and chilling Cross-contamination of the hands of workers and of equipment and utensils can spread the bacterium to uncontaminated carcasses and parts, contamination continuing during subsequent processing, cut-up and preparation activities. Besides, eggs, milk, water and some non-animal origin foods like coconut, barley, cereal powder, veast cottonseed chocolate candy soybean sauce, cider watermelon, white pepper, black pepper and carmine dye have been identified as vehicles of

there is the contract of the c

salmonellae. The importance of Salmonella in foods in international trade is comprehensively reviewed by D'Aoust (1994).

The minimal growth temperature is important in refrigerated foods. The growth rate of salmonellae is substantially reduced at < 15°C, while the growth of most salmonellae is prevented at <7°C. Slow growth in foods that are stored for extended periods in chilled conditions (but within the growth range for salmonellae) is of particular concern. Storage of perishable foods at temperatures below the minimum for growth is essential for safety. As the maximum temperature for growth is exceeded, death occurs. The rate increases with increasing temperature. The maximal growth temperature (49:5°C) is important as a value above which hot-stored foods must be maintained t prevent the growth of salmonellae. Although 55°C would suffice, 63°C is often specified in regulations. Although freezing can be detrimental to salmonellae, it does not guarantee destruction of salmonellae in food. Salmonella are sensitive to heat and heat-resistant strains are rare. An example is the unique strain 775W of S. seftenberg, which is considerably more resistant than other salmonellae in moist foods. Heat resistance is influenced by the water activity, nature of the solutes and pH of the suspending medium. Heat resistance increases as the water activity of the substrate decreases. Reducing pH reduces heat resistance.

Although salmonellae do not form spores, they can survive for long periods in foods and other substrates. Salmonellae survived longer than 10 weeks in butter stored at temperatures between - 23 and 25°C (Sims et al., 1969) and for 6 months in milk stored at room temperature or in an ice box (Berry, 1927). On a range of vegetables, including green beans, beets, cabbage, carrots, celery, cucumbers, lettuce, peppers, radish, spinach and tomatoes,

salmonellae consistently survived for more than 28 days at 2-4°C and about half that time at room temperature (Felsenfeld and Young, 1945). Their survival in the dry environment of chocolate is remarkable, numbers declining only slightly over months in milk chocolate (a<sub>w</sub> = 0.32-0.41) or bitter chocolate (a<sub>w</sub> = 0.30-0.51) (Tamminga, et al., 1977). Salmonellae also survive well on surfaces such as ceramic, glass and stainless steel (MeDade and Hall, 1964) and on human skin (Pether and Gilbert, 1971).

Since low numbers of salmonellae can cause illness, it is important to ensure their absence from ready-to-eat foods (Bryan, 1981). The major control procedures involve: A kill step to assure the destruction of salmonellae in contaminated foods, especially raw agricultural products of animal origin, prevention of contamination of ready-to-eat foods with salmonellae and low-, or high-temperature storage of foods that prevent the growth of salmonellae. The consequences of these bacteria in poultry products causing human illnesses will continue unless some means is devised and implemented that will either eliminate these bacteria from poultry or drastically reduce their contamination.

# 2.5 MEASURES TO CONTROL MICROORGANISMS ON POULTRY SURFACE

There is an immediate need for a cost-effective approach to reducing the prevalence of spoilage and pathogenic microorganisms on poultry to make it safer and more shelf-stable. Efforts to eliminate or substantially decrease bacterial populations on poultry have been made by the poultry industry. A variety of antimicrobial treatments for broiler carcasses have been investigated, with primary focus on those that are practical and effective. Major technologies that are employed to ensure the microbiological safety of poultry include (i) procedures that prevent the access of microorganism, (ii) procedures that

inactivate them should they have gained access, and (iii) procedures that prevent or slow down their growth should they have gained access and not been inactivated. Traditional preservation procedures act in one of these three ways.

#### Hot water

The USDA's Food Safety and Inspection Service (FSIS) recently approved the use of hot water (".....heated to any temperature provided sufficient safeguard exist") as an acceptable antimicrobial treatment during final washing of carcass (USDA, 1994a). However, hot water immersion study by Cox et al. (1974) demonstrated that broiler carcasses subjected to 60°C water treatment exhibited a partially cooked appearance.

Complete the second of the first of the second of the second

#### Chlorine

One approach has been the application of decontamination treatments to carcasses during processing (Todd, 1980). During poultry slaughtering, birds are killed, defeathered, eviscerated, cleaned and chilled by immersion in cold water. Currently, chlorine is used in chiller water to reduce microbial populations on poultry carcasses during immersion. Chlorine is used because of its generally recognized as safe (GRAS) status, efficacy, availability and relatively low cost (Tsai et al., 1991). However, production of off flavor, carcass discoloration and possible formation of chlororgenic compounds as a result of exposing poultry to free chlorine (Cunningham and Lawrence, 1977) has prompted a need for investigating alternative methods to decontaminate carcasses.

# interfere <mark>Hydrogen peroxide</mark> i sagerar late of their final relating the electric field in section .

Hydrogen peroxide at 6,600 ppm or higher in chiller water has been shown to reduce populations of aerobic microorganisms by 95-99.5% 5,300 ppm or higher reduced populations of *Escherichia coli* by 97-99.9 % (Lillard and

Thomson, 1983). However, the reaction of hydrogen peroxide with catalase from broiler carcasses causes discoloration and swelling (Hwang and Beuchat, 1995). Fletcher, et al., (1993), in a three-step rinse process using sodium bicarbonate and hydrogen peroxide solutions to decontaminate broiler surface achieved only 0.3 log<sub>10</sub> reduction. He observed that it is questionable whether the level of bacterial reduction would justify the use of such a procedure in lieu of other available methods.

#### Trisodium phosphate (TSP)

A process using food-grade orthophosphate (TSP) to reduce viable Salmonella spp. on chicken carcasses has been approved by USDA (Gies , 1993). This process has been reported to reduce populations of Salmonella spp. (Geise, 1993; 3M, 1994), E. coli (Geise, 1993), Campylobacter (Stern, et al., 1985) and S. aureus (Lee, et al., 1994) on chicken, but the population reduction on total aerobic microorganisms (3M, 1994) is much less.

Link to the the trade of the second

# Organic acids

Organic acids have been investigated because of their bactericidal activity and because they are generally recognized as safe (GRAS). They are utilized as preservatives in many food applications. Mountney and O'Malley (1965) studied the use of organic acids to increase the shelf-life of poultry. Acids were most effective in the following order acetic, adipic, succinic, citric, fumaric, and lactic, but the use of acetic acid caused the skin of the poultry to be hard and leathery. Reynolds and Carpenter (1974) also noticed discoloration and residual off-odor in pork carcasses treated with 2.32 M acetic acid. Lactic acid (1%) reduced Salmonella typhimurium from pure cultures and from inoculated broiler carcasses (Mulder et al., 1987); however, such treatment was later shown to

discolor the meat (Izat et al., 1989). Citric acid was found to be most inhibitory to Salmonella and as little as 0.3 % citric acid lowered the level of these organisms on poultry carcasses (Thomson et al., 1967). Further evaluation of organic acids may provide an economical and effective means of controlling microbial contamination during processing.

## Other chemicals

Treatment with ozone (Sheldon and Brown, 1986), potassium sorbate (Robach and Sofos, 1982), chlorine dioxide (Lillard, 1980; Thiessen et al., 1983), sodium lactate (Zeitoun and Debevere, 1980) and glutaraldehyde (Thomson et al., 1977) have been shown to reduce microbial population on poultry carcasses. However, factors such as cost or adverse sensory changes that can result from treatment with these chemicals has prevented their usage (Hwang and Beuchat, 1995).

#### <u>Irradiation</u>

lonizing radiation is effective in decontaminating poultry carcasses (Mulder et al., 1977) but its application may be limited by consumer acceptance. Moreover, it has a high initial capital expense and is difficult to incorporate in existing processing line.

# Modified Atmosphere Packaging/Vacuum packaging

The use of modified atmosphere packaging for extension of shelf life of fresh poultry was investigated (Finne, 1982) with some success. Huang (1978) observed slower growth rate of spoilage microorganism in chicken cut-up parts in vacuum packaging. However, there is a big risk of growth of any facultatively anaerobic or anaerobic psychrotrophic pathogen. Also, the process is expensive for a product like fresh chicken.

#### Other control measures

Ultrasonic energy (Sams and Feria, 1991) and ultraviolet radiation (Stremer et al., 1987) treatments have also been considered, but were ineffective for products with irregularly shaped surfaces. Other potential non-thermal methods to extend shelf life such as, Pulsed Electric Fields(PEF) and Pulsed High-intensity Light (PHIL) technology (Yousef, 1996), High Hydrostatic Pressure (HHP) Raffalli et al., 1994), Bacteriocins (Shefet, et al., 1995) etc. were studied with limited success. Flash steam heating followed by evaporative cooling (Morgan, et al., 1996, Cygnarowicz-Provost, 1994) was reported to be effective in some cases. These methods are not yet fully developed nor commercially applied.

人名斯内特拉马克斯特 医克勒氏病

JORNA GARAGO MARION O W

# 2.6 CITRIC ACID AND SODIUM CITRATE AS ANTIMICROBIAL ADDITIVES

Citric acid is a tricarboxylic acid having a pleasant sour taste and is found in a variety of natural foods. It is highly water soluble and enhances the flavor of citrus-based foods. It is approved for use in ice cream, sherbets and ices, beverages, salad dressings, fruit preserves, and jams and jellies, and it is used as an acidulant in canned vegetables and dairy products. It is a precursor of diacetyl and therefore indirectly improves the flavor and aroma of a variety of cultured dairy products. It can control the pH for optimum gel formation. Citric acid also acts synergistically with antioxidants to prevent rancidity by chelating metal ions (Gardner, 1972). Citric acid is approved as a GRAS substance for miscellaneous and general-purpose usage, in the acid form (21 CFR 182.1033) or as the calcium (21 CFR 182.1195), potassium (21 CFR 182.1625), or sodium salt (21 CFR 182.1751) (Code of Federal Regulations, 1977).

Murdock (1950) reported that citric acid was particularly inhibitory to flat-sour organisms isolated from tomato juice. Little bacteriostatic, activity was noted at pH 5.0, but with lowering of pH level, the inhibition increased. Fabian and Graham (1953) compared citric, acetic, and lactic acids with respect to inhibition of thermophilic bacteria. Citric was the acid of choice, followed by acetic and lactic. Skim milk acidified with hydrochloric, lactic, or citric acid was inoculated with S. typhimurium. Citric acid was found to the most inhibitory to the salmonellae, followed by lactic and hydrochloric acids (Subramanian and Marth, 1968).

Concentrations of 12-12.5% sodium citrate were inhibitory to *S. anatum* and *S. oranienburg* (Davis and Barnes, 1952). As little as 0..3% citric acid lowered the level of salmonellae on poultry carcasses (Thomson et al.,1967). Sodium citrate in concentrations of 0.1-4.0% were not inhibitory to *Streptococcus agalactiae* when added to skim milk or fresh milk; however, citric acid at 1, 2, and 4% was inhibitory. The minimum inhibitory concentration was judged to be 0.8%, which gave a pH of 4.08-4.12 (Sinha et al., 1968). The amount of sodium citrat had a dual effect on *Lactobacillus casei* (Imai, et al., 1970). In concentrations of 12-18 μM/ml, sodium citrate was found to be stimulatory, whereas in concentrations greater than 40 μM/ml, *L. casei* was inhibited. Chelation of metal ions by citrate may be the cause of the inhibition (Branen and Keenan, 1970). Experiments using *S. aureus* showed inhibition both with increasing concentrations of citrate and decreasing pH. It was believed that citrate was a chelator of ions essential for growth. Inhibition by citrate could be overcome by adding Ca<sup>2+</sup> and Mg<sup>2+</sup> ions (Rammell, 1962).

#### 2.7 HEAT PASTEURIZATION

Heat treatment and low temperature storage are two of the main methods of food preservation. Refrigeration has the advantage of leaving organoleptic properties and nutritive value of foods almost unchanged. However refrigeration does not necessarily ensure food safety. Heat, with its destructive effect on microorganisms ensures safety and longtime preservation, but the effects of heat on foods can also be very detrimental. Some thermal processings cause significant drastic changes in organoleptic properties and reductions in nutritive value. As no other method of food preservation to replace heat has yet been developed, a new approach in food preservation has arisen. This is th combination of heat with other methods that together enhance the lethal effect of heat on microorganisms and result in a lowering of the intensity of conventional heat treatments. This approach has lately revived the interest of scientists in what has become known as the 'preservation of foods by combined processes'.

Although the preservation of foods by combined processes is not new, the advance of scientific knowledge has opened new possibilities: the influence of different microenvironmental parameters on the heat resistance of microorganisms is now much better known and new lethal effects of some physical phenomena have been reported. For example, the combination of heat and reduced pH to lower microbial heat resistance allowed the use of milder heat treatments and was one of the first combined processes to be employed. Other combinations widely used are those with sodium chloride, nitrite, etc. More recently, technological advances have led to the investigation of other possible combinations: These include the combination of heat with ultrahigh pressures, which attracted the interest of many research groups world-wide (Gould, 1973)

and, most recently, the combination of heat with antimicrobial preservatives like organic acids. The antimicrobial activity of these acids is w Il-documented (Doores, 1983). Cell walls, cell membranes, metabolic enzymes, protein synthesis system and genetic material are the main targets of their action against wide range of microorganisms.

With respect to the improvement of techniques for the inactivation of microorganisms in foods, most effort and new application has concerned thermal processing. A particular aim has been to minimise damage to product quality. This is being pursued in two, often complementary, ways. Firstly, by the wider application of more high temperature short time processing, with associated aseptic packaging where relevant. Secondly, by delivering heat in new ways, e.g. by microwaves or by electrical resistance ("ohmic") heating of foods, which allow better control of heat delivery and minimize the over-cooking that commonly occurs in more conventional thermal processes.

# 2.7.1 HEAT INACTIVATION OF MICROORGANISMS

Inactivation of microorganisms by heat is a fundamental operation in food preservation (Toledo, 1993). Although Nicholas Appert first performed the preservation of foods by heat in France around 1810, this remained for a long time an empirical practice until the scientific knowledge on the mechanism of the preservation effect began to accumulate. The works of Bigelow (1921) finally established the sound basis on which, still today, current methods of heat preservation rely.

The observation by Bigelow that the death of microorganisms followed a first order reaction kinetic pattern was essential for the future development of the technology of food preservation by heat. Bigelow showed that every unit of

heating time of a microbial population at a given temperature reduced the number of viable cells by a constant proportion. By plotting the log of the number of survivors as a function of heating times, a straight line is therefore obtained. In this plot (survival curve), the minutes needed to reduce the number of viable cells to 1/10 (one log cycle) of its original value is now known as the 'decimal reduction time', or  $D_t$  value. When log  $D_t$  values are plotted vs. their corresponding heating temperatures (Decimal Reduction Time Curve; DRTC), again a straight lin is obtained. The number of degrees Celsius of temperature increase for the log  $D_t$  value to decrease by one log cycle is known as z value. The heat resistance of microorganisms is defined by these two parameters. Once a  $D_t$  value is known, the kinetics of death (Survival curve) allows prediction of the numbers of survivors after a given heating time. Furthermore, as z value allow the calculation of the lethal effect of each temperature; the total lethal effect of any given process, including heating and cooling phases, can be estimated, thus avoiding undue overprocessing.

Work carried out by food microbiologists on the influence of different factors on heat resistance of micro-organisms and on the kinetics of death, has led to some authors to question the validity of some published heat resistance data (Dt and z values), once considered as well defined and constant parameters are in fact very variable, being influenced by many factors. For example, the pH of heating menstruum is one of the most important and one of the firsts to be known. But many others, such as the water activity (a<sub>w</sub>) (Alderton et al., 1980); sporulation temperature (Beaman and Gerhardt, 1986; Condon et al., 1992b) and growth medium (Donnelly and Busta, 1980), composition of heating medium

(Blocher and Busta, 1983; Condon and Sala, 1991) and incubation temperature and medium after heat treatment (Cook and Gilbert, 1968; Feeherry et al., 1987) have also been investigated. Some heat resistance data reported in literature should therefore be accepted with caution as factors influencing these data were unknown to the authors or not taken into account. The effect of some influencing factors can be so big as to make the differences in heat resistance between two populations of the same strain, bigger than those between two unrelated species (Put and Aalbersberg, 1967). The capacity of different parameters to strongly influence the heat resistance of micro-organisms is currently an important issue in thermobacteriology, as are the deviations from theoretical death rate kinetics, such as those reported by some authors on survival curves and DRTC. Among different deviations reported on the patterns of survival curves (Moats et al., 1971; Brown and Ayres, 1975), 'tails' and 'shoulders' are the most frequent and best characterised. A combination of both can explain most, if not all deviations of linearity of survival curves.

Tails' are end portions of survival curves that appear with a decreasing slope at the final stages of heating. A comprehensive review of the 'tail' phenomenon is that of Cerf (1977). The different hypotheses to explain this phenomenon have been classified by Cerf into two groups of theories; 'vitalistic' and 'mechanistic'. 'Vitalistic theories' try to explain deviations from linearity of survival curves by postulating a different heat resistance for each individual cell in a population. 'Mechanistic theories' assume a logarithmic death rate and blame the appearance of deviations to methodological artefacts (Stumbo, 1973) or to the development of a higher heat resistance during heat treatments (Mackey and Derrick, 1986a). The development of a higher heat resistance of

vegetative cells during heat treatments, reported by different authors, would be due to metabolic changes (Mackey and Derrick, 1986b) or to interactions with the heating menstruum. Although the fraction of the population having a higher heat resistance is normally very small, its heat resistance can be so high that it can become the factor determining the intensity of heat treatments (Moats et al., 1971; Condon et al, 1992a). Current concern to reduce the intensity of heat treatments in order to improve the quality of food products has led to a more detailed study of death rate kinetics and to model heat treatments in such a way as to take into account deviations of logarithmic death rate (Cole et al., 1993).

'Shoulders', appear in the first portion of the survival curves, with different shapes. In 'shoulders' the slope of survival curves is always smaller and sometimes the number of survivors not only does not decrease, but also can even increase. This phenomenon is less frequent in vegetative cells and some authors have related it to cell clumps desegregation (Hansen and Riemann, 1963). 'Shoulders' are much more frequent in spore suspensions. In some authors' opinions (Shull et al., 1963; Lewis et al., 1965), in spores, 'shoulders' are often caused by a lack of 'activation'. A high proportion of a spore population is often unable to germinate. The spores are in a latent ('dormant') state. Som chemical/physical treatments can 'activate' them, restoring their germination capacity. Heat is a well-known activation agent. During the first moments of a heat treatment two opposite phenomena therefore take place, each at a different rate and both catalyzed by heat: the activation of 'dormant spores' and the concurrent and subsequent inactivation of all spores. It is now believed that activation follows, as does heat inactivation, first-order reaction kinetics

and produced by an emphasis of the first of the control of the con

(Abraham et al., 1990; Sapru et al., 1993). The balance between both rate constants would determine the profile of 'shoulders'.

In the last 35 years, attempts have been made to develop mathematical models of death rates that would include 'shoulders'. Shull et al. (1963), in his attempt to develop the first model, postulated that activation and heat inactivation were two separate and successive phenomena. Other authors (Abraham et al., 1990) who also postulated that activation is in fact the limiting factor of the inactivation phenomenon also shared this opinion. On the contrary, other authors (Rodriguez et al., 1991; Sapru et al., 1992) believed that both phenomena are simultaneous and a prior 'activation' is not necessary for spores to be inactivated by heat. There is no agreement about whether the heat resistance of activated and dormant spores is the same. While some have developed mathematical models assuming equal heat resistance (Rodriguez et al., 1991), the models of others assume that they are different (Sapru et al., 1993).

Other deviations of linearity of death kinetics in DRTC have also be nareported. However, these are less known and there is no agreement among authors. While some investigators have reported that z values increase at higher temperatures of treatment (DRTC curves bend upwards) (Wang et al., 1964; David and Merson et al., 1990) others have reported that they decrease (Cerf and Hermier, 1973; Hermier et al., 1975). In some authors opinion (Cerf and Hermier, 1973) the decrease of  $D_t$  values at high temperatures of treatment could be due to a thermal shock that would be greater the higher the temperature of treatment, causing the DRTC to bend downwards (decreasing z values). According to these authors the higher  $D_t$  and z values at higher temperatures

reported in literature would be explained by methodological errors. Difficulti s in the measurement of the very short heating times involve in high temperature treatments would result in poor estimations of heating times. Much therefore remains uncertain about heat resistance and death kinetics.

Despite substantial efforts carried out during the last half of this century, the mechanism(s) of heat inactivation are not yet clear. According to the first interpretation, the strict logarithmic order of death, as postulated by Bigelow, could most easily be explained by a mechanism involving the destruction of one single or a small number of vital molecules per cell. As the kinetics of cell death have become better known many authors have attempted to explain deviations from linearity by implying in these mechanism different vital molecules and/or structures. Heat has been reported to damage different cell structures, including damage to cell membranes, ribosome, DNA, RNA and enzymes. DNA is still considered the most likely lethal target molecule, but damage occurring at the same time in different molecules and/or structures may also result in heat inactivation. Some of these injuries can be repaired and ultimately it is the balance of intensity of injury/capacity to repair that determines cell viability. A more detailed review of the mechanisms of microbial heat inactivation and injury is that of Gould (1989).

## 2.7.2 PHYSICS OF HEAT TRANSFER

When heat is exchanged between matter, or parts of the same matter, it is called heat transfer. Heat transfer always occurs from warm to cool. It is generally transferred by one, or a combination, of three processes: conduction, convection and radiation (Lawton and Klingenberg, 1996)

tigas filologicas in ligitor til tradegica i til lakera i latiga i til later i gran läkade filologica salad tr

Conduction: If heat is applied directly to one part of a solid object, the electrons become excited. This causes molecular collisions, which travel along the object, heating as it passes through. This transfer of heat within a solid is known as conduction and the ability to transfer heat within an object is called thermal conductivity. It varies for different materials. Gold, silver and copper have high thermal conductivity. These materials are also good conductors of electricity. Other materials, such as glass and mineral wool, have low thermal conductivity. This quality makes them good insulators.

Convection: Conduction between objects, where one is a gas or liquid, is called convection. As gasses or liquids are heated, the excited molecules achieve a fluid motion. Where gravity is a factor, such as here on earth, the natural fluid motion moves the heated, less dense molecules up and the cooler, more compact molecules down. The fluid motion of the gas or liquid molecules may also be forced by a current of air, for example.

Radiation: The transmission of energy across space is called radiation. Radiation does not depend on the presence of matter and can occur across a vacuum. Radiant heat transfer generally involves the range of electromagnetic waves called infrared radiation. All matter releases radiant energy. Hotter matter releases more radiant energy than cooler matter.

Infrared radiation (IR): IR energy is emitted by all materials above 0°K (Toledo, 1993). Infrared radiation is part of the Electromagnetic Spectrum and occupies frequencies between visible light and radio waves. The IR part of the spectrum spans wavelengths from 0.7 micrometers to 1000 micrometers (microns). Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement. This is because the IR detectors

currently available to industry ar not sensitive enough to detect the very small amounts of energy available at wavelengths beyond 20 microns (Siegel and Howell, 1992).

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects which are opaque to the human eye, part of the IR energy striking the object's surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a proportion will be re-emitted and part will be reflected internally. This will also apply to materials which are transparent to the eye, such as glass, gases and thin, clear plastics, but in addition, some of the IR energy will also pass through the object. These phenomena collectively contribute to what is referred to as the *Emissivity* of the object or material (Sala, 1986)

Materials which do not reflect or transmit any IR energy are known as blackbodies and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0, which can be achieved in real life is an IR opaque, spherical cavity with a small tubular entry. The inner surface of such a sphere will have an emissivity of 0.998. Different kinds of materials and gases have different emissivities, and will therefore emit IR at different intensities for a given temperature. The emissivity of a material or gas is a function of its molecular structure and surface characteristics. It is not generally a function of color unless the source of the color is a radically different substance to the main

body of material. A practical example of this is metallic paints which incorporate significant amounts of aluminum. Most paints have the same emissivity irrespective of color, but aluminum has a very different emissivity which will therefore modify the emissivity of metallized paints. (Hottel and Sarofim, 1967).

Just as is the case with visible light, the more highly polished some surfaces are, the more IR energy the surface will reflect. The surface characteristics of a material will therefore also influence its emissivity. In temperature measurement this is most significant in the case of infrared opaque materials which have an inherently low emissivity. Thus a highly polished piece of stainless steel will have a much lower emissivity than the same piece with a rough, machined surface. This is because the grooves created by the machining prevent as much of the IR energy from being reflected.

The laws upon which infrared temperature measurement is based are old, established and well proven (Lawton and Klingenberg, 1996). These are as follows:

- 1. Kirchoff's Law (1860): When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.
- 2. Stephan Boltzmann Law (1879): The hotter an object becomes the more infrared energy it emits.
- 3. Wien's Displacement Law (1896): The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.
- 4. Planck's Equation (1900) Describes the relationship between spectral emissivity, temperature and radiant energy.

The Company of Springer (1994) and the

#### REFERENCES

and the second of the second o

- 1. Abraham, G., Debray, E., Candau, Y. and Piar, G. 1990. Mathematical model of thermal destruction of *Bacillus stearothermophilus* spores. *Applied and Environmental Microbiology*, 56: 3073-3080.
- 2. Alderton, G., Chen, J.K. and Ito, K.A. 1980. Heat resistance of the chemical resistance forms of *Clostridium botulinum 62A* spores over the water activity range 0 to 0.9. *Applied and Environmental Microbiology*, 40: 511-515.
- 3. American Meat Institute, 1991. Annual report. Washington, D. C.
- 4. Anon. 1998. Chicken: what you don't know can hurt you. *Consumer Reports*, 63(3): 12-18.
- Archer, D. L. and Young, F. 1988. Contemporary issues. Diseases with a food vector, Clinical Microbiology Reviews 1: 337-398.
- 6. Ayres, J. C. 1959. Effect of sanitation, packaging and antibiotics on the microbial spoilage of commercially processed poultry. *Iowa-State J. Sci.* 34: 27-46

多点键制 经收益的股票 人名阿特克伊伊多尔巴萨马克

- 7. Bailey, J.S., Cox, N.A. and Blankenship, L.C. 1990. Persistence and spread of external *Salmonella* during broiler production. *Poultry Science*. 69: 154-159.
- 8. Barnes, E. M. 1976. Microbiological problems of poultry at refrigeration temperatures A review. J. Sci. Fd. Agric. 27: 777-786
- 9. Barnes, E.M. and Impey, C.S. 1969. Psychrophilic spoilage bacteria of poultry. J. Appl. Bacteriol. 31: 97-102
- 10. Barnes, E.M., & Thornley, M.J. 1966. The spoilage flora of eviscerated chickens stored at different temperatures. *Journal of Food Technology*, 1: 113-119.
- 11. Barnes, E.M. 1976. Microbiological problems of poultry at refrigerator temperatures a review. *Journal of the Science of Food and Agriculture*, 27: 777-782.
- 12. Barnes, E.M. 1960. Sources of different psychrophilic spoilage organisms on chilled eviscerated poultry. *Proceedings of the Tenth International Congress of Refrigeration*, Copenhagen, 3: 97-100.

- Beaman, T.C. and Gerhard, P. 1986 Heat resistance of bacterial spores **13**. correlated with protoplast dehydration, mineralization and thermal adaptation. Applied and Environmental Microbiology, 52: 1242-1246.
- Berry, A. E. 1927: Viability of pathogenic organisms in butter. Journal of 14. Preventive Medicine 1: 429-442.
- Bigelow, W. D. 1921. The logarithmic nature of thermal death-time curves. **15**. Journal of Infectious Diseases, 28: 528-532.
- Black, R. E., Levine, M. M., Blaser, M. J., Clements, M. L. and Hughes, T.P. 16. 1983. Studies of Campylobacter jejuni infection in volunteers. Pearson, M. B. Skirrow, B. Rowe, J. R. Davies, and D. M. Jones (eds) Campyiobacter II, London: Public Health Laboratory Service: 13.
- Blaser, M. J. and L. S. Newman. 1982. A review of human salmonellosis: I. 17. Infective dose. Rev. Infect. Dis. 4: 1096-1106.

- Blaser, M. J., Taylor, D.N. and Feldman, R.A. 1984. Epidemiology of 18. Campylobacter infections. In 'Campylobacter Infections', in Butzler, J. P. (ed.) Man and Animals, Boca Raton, Fla: CRC Press: 143-161.
- 是基本的企业的 人名比 (A) (A) (A) (A) (A) (A) (A) Blocher, J.C. and Busta, F.F. 1983. Bacterial spore resistance to acid. Food 19. Technology, 11: 87-99.
- 20. Bolton, F.J., Hutchinson, D.N. and Coates, D. 1986. Comparisons of thre selective agars for isolation of campylobacters. European Journal of Clinical Microbiology 5: 466-468.
- 21. Branen, A. L. , Davidson, P. M. I and Katz, B. 1980. Antimicrobial properties of phenolic antioxidants and lipids. Food Technol. 34(5): 42-49.

10.0

- 22. Branen, A. L., and Kennan, T. W. 1970. Growth Stimulation of Lactobacillus casei by sodium citrate. J. Dairy Science. 53: 593-600.
  - Application of the second second Brenner, D. J. 1984. Facultatively anaerobic gram-negative rods. In Krieg, N. **23**. R. and Holt, J. C. (eds.) Bergey's Manual of Systematic Bacteriology, (Vol. 1), Baltimore: Williams and Wilkins. 408-516.
- 24. Brown K. L. and Ayres, C. A. 1985. Thermobacteriology of UHT processed foods. In Developments in Food Microbiology (ed. R. Davies), Applied Sciences Publishers, London, pp. 119-152.
- 25. Bryan, F. L. 1980. Foodborne diseases in the United States associated with the man and poultry. J. Food Prot. 43: 140-150.

26. Bryan, F. L. 1981. Current trends in salmonellosis in the United States and Canada. *Journal of Food Protection* 44: 394-402.

The contract of the contract o

- 27. Bryan, F. L. and M. P. Doyle. 1994. Health Risks and Consequences of Salmonella and Campylobacter jejuni in Raw Poultry. J. Food Protection. 58(3): 326-344.
- 28. Budd, W. 1874. Typhoid Fever. Its Nature, Modes of spreading and prevention (reprinted 1977). New York: Arnold Bress.
- 29. CDC (Center for Disease Control). 1988. Campylobacter isolates in th United States, 1982-1986. Morbid. Morbid. Weekly Rep. 37 (no. SS-2): 1-13.
- 30. Cerf, O. and Hermier, J. 1973. Thermoresistance anormale de spores bacteriennes chauffees par injection directe dans la vapeur. Le lait, 43: 23-29.
- 31. Cerf, O. 1977. Tailing of survival curves of bacterial spores. *Journal of Applied Bacteriology*, 42: 1-19.

Association and the second

- 32. Chalker, R. B. and M. J. Blaser. 1988. A review of human salmonellosis: III Magnitude of Salmonella infection in the United States. Rev. Infect. Dis. 10: 111-124.
- 33. Coates, D., Hutchinson, D. N. and Bolton, F. J. 1987. Survival of thermophilic campylobacters on fingertips and their elimination by washing and disinfection, *Epidemiology and Infection*, 99:265-274.
- 34. Code of Federal Reulations, Title 21, Sections 182.1033, 182.1195, 182.1625, and 182.1751, Foods and Drugs. 1977, US Government Printing Office, Washington, DC.
- 35. Cole, M. B., Davies, K. W., Munro, G., Holyoak, G. D. and Kilsby, D. C. 1993.

  A vitalistic model to describe the thermal inactivation of *Listeria monocytogenes*. *Journal of Industrial Microbiology*, 12: 232-239.
- 36. Condon, S. and Sala, F. J. 1991. Heat resistance of Bacillus subtilis in buffer and foods of different pH. Journal of Food Protection, 55: 605-608.
- 37. Condon, S., Garcia, M. L., Otero, A. and Sala, F. J. 1992a. Effect of culture age, preincubation at low temperature and pH on the thermal resistance of Aeromonas hydrophila. Journal of applied Bacteriology, 72: 322-326.
  - 38. Condon, S., Bayarte, M. and Sala, F. J. 1992b. Influence of the sporulation temperature upon the heat resistance of *Bacillus subtilis*. *Journal of Applied Bacteriology*, 73: 251-256.

- 39. Cook, A. M. and Gilbert, R. J. 1968. Factors affecting the hat resistance of B. stearothermophilus spores. Journal of Food Technology, 3: 385-393.
- 40. Cox, N. A., Mercuri, A.J., Thompson, J.E., and Gregory, D.W. Jr. 1974. Quality of broiler carcasses as affected by hot water treatments. *Poultry Sc.*
- 41. Cunningham, F. E., and Cox, N. A. 1987. The Microbiology of Poultry Meat Products, Academic Press, New York.
- 42. Cunningham, F. E. 1982. Microbiological aspects of poultry products An update. *J. Food Prot.* 45, 1149.
- 43. Cunningham, H.M. and Lawrence G.A. 1977. Effect of exposure of meat and poultry to chlorinated water on the retention of chlorinated compounds and water. J. Food Sci. 42: 1504-1508.
- 44. Cunningham, F.E. 1987. Chap.3 in The Microbiology of poultry meat products, Academic Press, Inc., Orlando, Florida.
- 45. Cygnarowicz-Provost, M., Whiting, R.C., and Craig, J.C. Jr. 1994. Steam surface pasteurization of beef frankfurters. *J. Food Sci.* 59(1): 1-5.
  - 46. D'Aoust, J. Y. 1994. Salmonella and the international food trade. International J. Food Microb. 241: 11-31.
- 47. D'Aoust, J. Y., and Pivnick, H. 1976. Small infectious doses of Salmonella. Lancet 1: 866.

- 48. Davis, F. and Barnes, L. A. 1952. Suppression of growth of Salmonella anatum and Salmonella oranienburg by concentration variation of energy source in a synthetic basal medium. J. Bacteriol. 63: 33-38.
- 49. David, J. R. and Merson, R. L. 1990. Kinetic parameters for inactivation of Bacillus stearothermophilus at high temperatures. Journal of Food Science, 55: 488-493.

ing makan di linggipang mema<mark>ngana</mark>ng ang milihan kalang habip, melalikanan giliging di bing palah s

The Carrier and the Grands are entired by the determination of the foreign control of the control of the control of

an the relation represents the filter of the new party of the filter and the second

- 50. Davidson, P. M., and Branen, A. L. 1981. Antimicrobial activity of non halogenated phenolic compounds. *J. Food Prot.* 44: 623-628.
- 51. Dickson, J. S. 1992. Acetic acid action on beef tissue surface contaminated with Salmonella typhimurium. J. Food Science. 57(2): 297-301.
- 52. Donnelly, L. S. and Busta, F. F. 1980. Heat resistance of Desulfotomaculatum nigrificans in soy protein infant formula preparations. Applied and Environmental Microbiology, 40: 727-735.

- 53. Doores, S. 1993. Organic acids, p. 95-136. In A. L. Branen and P. M. Davidson (eds.) *Antimicrobials in foods*. Marcel Dekker, Inc. New York, NY.
- Doyle, M. P. 1984. Campylobacter in foods. In J. P. Butzler (ed.)

  Campylobacter Infections in Man and Animals, Boca Raton, Flat CRC Press:
  163-180.
- 55. Dubert, W. H. 1988. Assessment of *Salmonella* contamination in poultry past, present, and future. *Poultry Sci.* 67: 944-949.

Note that the state of the stat

- 56. Elliott, P. H., Tomlins, R.I., and R. Gray, R.J.H.. 1995. Control of Microbial Spoilage on Fresh Poultry using a Combination Potassium Sorbate/ Carbon Dioxide Packaging System. J. Food Science. 50: 1360-1163.
- 57. Ewing, W. H. 1986. The taxonomy of Enterobacteriaceae, isolation of Enterobacteriaceac and preliminary identification. The genus Salmonella. In Edwards, P. and Ewing, W. H. (eds.) Identification of Enterobacteriaceae (4th ed.), New York, Elsevier, 1-94, 181-318.
- 58. Fabian, F. W., and Graham, H. T. 1953. Viability of thermophilic bacteria in the presence of varying concentrations of acids, sodium chloride and sugars. Food Technol. 7: 212-217.
  - 59. Feeherry, F. E., Munsey, D. T. and Lowley, D. R. 1987. Thermal inactivation and injury of *Bacillus sterarothermophilus* spores. *Applied and Environmental Microbiology*. 53: 365-370.
- 60. Felsenfeld, O. and Young, V. M. 1945. The viability of Salmonella on artificially contaminated vegetables. *Poultry Science* 24: 353-355.

- 61. Finne, G. 1982. Modified and controlled atmosphere storage of muscle foods. Food Technol. 36(2): 128-135.
- 62. Fischer, J.R., Fletcher, D.L. Cox, N.A., and Bailey, J.S. 1985. Microbiological properties of hard-cooked eggs in a citric acid-based preservation solution. *J. Food Protection*. 48(3): 252-256.

ergi frjaktifik om av kriger i er og til og av og grandfragt av nåretter blandte til bytale er

- 63. Fletcher, D. L., Russell, S.M. and Walker, J.M. 1993. An evaluation of a rinse procedure using sodium bicarbonate and hydrogen peroxide on the recovery of bacteria from broiler carcasses. Poultry Science, 72: 2152-2156.
  - 64. Food and Drug Administration. 1979. Specific food labeling requirements. Food and Drug Administration. Code of Federal Regulations, Title 21, Paragraph 101.22(a).

- Franco, D. A., and Williams, C. E. 1994. Campylobacter jejuni, p. 71-96. In Y. H. Hui, J. R. Gorham, K. D. Murrell, and D. O. Cliver (ed.), Foodborne disease handbook, vol.1, Diseases caused by bacteria, Marcel Dekker, Inc., New York.
- 66. Franco, D. A. 1989. Campylobacteriosis: the complexity of control and prevention. *Journal of Environmental Health* 1 52:88-92.
- 67. Fricker, C. R. 1984. Procedures for the isolation of Campylobacter jejuni and Campylobacter coli from poultry, International Journal of Food Microbiology 1: 149-154.
- 68. Fulton, K. R. 1981. Surveys of industry on the use of food additives. Food Technol. 35(12): 80-89.
- 69. Gardner, W. H. 1972. Acidulants in food processing. In *Handbook of Food Additives*, 2<sup>nd</sup> ed., edited by T. E. Furia. CRC Press, Cleveland, Ohio, p. 225.
- 70. Giese, J. 1993. Salmonella reduction process receives approval. Food Technol. 46(1): 110-116.
- 71. Gill, C. O. 1986. The control of microbial spoilage in fresh meats. In Advances in Meat Research, eds. A. M. Pierson and T. R. Dutson, Vol. 2, Meat and poultry microbiology, p. 1. AVI Publishing Co. Westport, Conn.
- 72. Gill, C. O. and Harris, L. M. 1984. Hamburgers and broiler chickens as potential sources of human Campyiobacter enteritis. Journal of Food Protection 47: 96-99.
  - 73. Gill, C.O. and Penney, N. 1977. Penetration of bacteria into meat. Applied and Environmental Microbiology . 33: 1284-1286.
  - 74. Gomori, G., and Gulyas, E. 1944. Effect of parenterally administered citrate on the renal excretion of calcium. *Proc. Soc. Exp. Biol. Med.* 56: 226-231.
    - 75. Gould, G. W. 1973. Inactivation of spores in food by combined heat and hydrostatic pressure. *Acta Alimentaria*, 2: 377-383.

The contract of the contract of the property of the contract o

76. Gould, G. W. 1989. Heat-induced injury and inactivation. In Mechanisms of action of food Preservation Procedures (ed. G. W. Gould), Elsevier Applied Science, London, pp. 11-42.

77. Grau, F. H. 1986. Microbial ecology of meat and poultry. *In* Advances in Meat Research, vol.2, *Meat and Poultry Microbiology*, eds. Pierson, A. M. and Dutson, T. R., AVI Publishing Co., Westport, Connecticut, 1-47.

1.

78. Hansen, N. J. and Riemann, H. 1963. Factors affecting the heat resistance of nonsporting organisms. *Journal of Applied Bacteriology*. 20: 314-318.

THE COURSE CONTRACTOR OF THE CONTRACTOR SHOWS THE CONTRACTOR OF TH

- 79. Harper, J. C. 1976. Chap.12 in <u>Elements of Food Engineering</u>, AVI Press, Westport, Connecticut.
- 80. Harris, N. V., Weiss, N.S., and Noland, C.M.. 1986. The role of poultry and meats in the etiology of Campylobacter jejuni/coli enteritis. Am. J. Public Health 76: 407-411.
- 81. Harrison, M. A. and S. L. Carpenter. 1989. Survival of large populations of Listeria monocytogenes on chicken breast processed using moist heat. J. Food Prot. 52: 376-378.
- 82. Hathcox, A.K., Hwang, C.A., Resurrecccion, A.V.A., and Beuchat, L.R. 1995. Consumer evaluation of raw and fried chicken after washing in trisodium phosphate or lactic acid/sodium benzoate solutions. *J. Food Science*. 60(3): 604-605, 610).
- 83. Hauschild, A.H.W. and Bryan, F.L. 1980. Estimate of cases of food- and water-borne illness in Canada and the United States. *J. Food Prot.* 43: 435-440.
- 84. Hood, A. M., Pearson, A.D. and Shahamat, M. 1988. The extent of surface contamination of retailed chickens with *Campylobacter jejuni* serogroups. *Epidemiol. Infect.* 100: 17-25.
- 85. Hottel, H.C. and Sarofim, A.F. 1967. "Radiation Transfer:" McGraw Hill, New York, NY.
- 86. Huang, Yao-Wen. 1978. Studies on the microbial quality of poultry meat. A thesis submitted to the Graduate Faculty of the University of Georgia for MS degree.
  - 87. Hwang, C., and Beuchat, L.R. 1995. Efficacy of Selected Chemicals for Killing Pathogenic and Spoilage Microorganisms on Chicken Skin. *J. Food Protection*. 58(1): 19-23.

"我们的我的感觉的,我们们就是一个人的现在分词,我们也从<sub>这</sub>是是不是这个人。"

88. Imai, K., Banno, I., and Iijima, T. 1970. Inhibition of bacterial growth by citrate. J. Gen. Appl. Micribiol. 16: 479-484.

- 89. ICMSF (International Commission of Microbiological Specifications for Foods) 1978. Microorganisms in Foods. I. Their Significance and Methods of Enumeration (2nd ed.), Toronto: University of Toronto Press: 160-72.
- 90. ICMSF (International Commission on Microbiological Specifications for Foods). 1980. Poultry and poultry meat products. Vol. 2. Food Commodities, p. 410. Academic Press, New York, NY.
  - 91. Istre, G. R., Blaser, M. J., Shiliam, P. and Hopkins, R. S. 1984. Campylobacter enteritis associated with undercooked barbecued chicken, American Journal of Public Health 74:1265-1267.
  - 92. Izat, A. L., Colberg, M., Adams, M.H., Reiber, M.A. and Waldroup, P.W.. 1989. Production and Processing studies to reduce the incidence of salmonellae on commercial broilers. *J. Food Prot.* 52: 670-673.
  - 93. Jay, J.M. 1992. *Modern Food Microbiology*. 4th ed. Chapman and Hall, New York.
  - 94. Johnson, W. M. and Lior, H. 1986. Cytotoxic and cytotonic factors produced by Campylobacter jejuni, Campylobacter coli, and Campylobacter laridis. Journal of Clinical Microbiology. 24: 275-281.
  - 95. Kaijser, B. 1988. Campylobacter jejuni /coli. APMIS 96: 283-288.
- 96. Kermode, G. 0. 1972. Food additives. Sci. Am. 226(3): 15-22.

性的概念。唯可能是确保的一点,可以可能可以以下的一种特殊的一点,也是编译的。可能像是一个种一种

 $\mathcal{L}_{i}^{1}(t,t_{i})$ 

- 97. Kraft, A. A. 1971. Microbiology of poultry products. *J. Milk Food Technol.* 34: 23-28.
- 98. Kraft, A.A. 1992. Psychrotrophic Bacteria in Foods: Disease and Spoilage. CRC Press, Inc. Boca Raton, Fla.
- 99. Lammerding, A. M., and Paoli, G.M. 1997. Quantitative risk assessment: an emerging tool for emerging foodborne pathogens. *Emerging Infectious Diseases*. 3(4).
- 100. Lamuka, P. O., Sunki, G.R., Chawan, C.B., Rao, D.R., and Shackelford, L.A. 1992. Bacteriological quality of freshly processed broiler chickens as affected by carcass pretreatment and gamma irradiation. *J. Food Science*. 57(2): 330-332.
  - 101. Lawton, B. and Klingenberg, G. 1996. "Transient temperature in Engineering and Science. Oxford University Press, Oxford, UK.

- 102. Lee, R. M., Hartman, P. A., Olson, D. G., and Williams, F. D. 1994.

  Bactericidal and bacteriolytic effects of selected food-grade phosphates, using Staphylococcus aureus as a model system. J. Food Prot. 57: 276-283.
  - 103. Lewis, J. C., Snell, N. S. and Alderton, G. 1965. Dormancy and activation of bacterial spores. In *Spores* III (eds. L. L. Campbell and H. 0. Halvorson), American Society for Microbiology, Washington, D.C., pp. 47-55.
  - 104. Lillard, H. S. 1980. Effect on broiler carcasses and water treating chill water with chlorine or chlorine dioxide. *Poultry Sci.* 59: 1761-1766.
  - 105. Lillard, H. S. 1980a. Bacterial cell characteristics and conditions influencing their adhesion to poultry skin. *J. Food Prot.* 98: 803-807.
  - 106. Lillard, H. S. 1982. Improved chilling systems for poultry. Food Technol. 36(2): 58.
  - 107. Lillard, H. S. 1988. Effect of surfactant or changes in ionic strength on th attachment of Salmonella typhimurium to poultry skin and muscle. J. Food Sci. 53: 727-730.
  - 108. Lillard, H. S. and Thomson, J.E. 1983. Efficacy of hydrogen peroxide as a bactericide in poultry chiller water. *J. Food Sci.* 48: 125-126.
  - 109. Lillard, H. S., Blankenship, L. C., Dickens, J. A., Craven, S. E., and Shackelford, A. D. 1987. Effect of acetic acid on the microbiological quality of scalded picked and unpicked broiler carcasses. *Journal Food Protection* . 50: 112-117.
- 110. Lillard, H. S. 1994. Effect of TSP on Salmonellae attached to chicken skin.

  Journal of Food Protection. 57: 465-469.
- 111. Lillard, H. S. 1990. Impact of commercial processing procedures on bacterial contamination of broiler carcasses. *Journal of Food Protection*, 53: 202-208.
- 112. 3M. 1994. Effect of trisodium phosphate on Salmonella attached to chicken skin. J. Food Prot. 57: 465-469.
- 113. Mackey, B. M. and Derrick, C. M. 1986a. Elevation of the heat resistance of Salmonella typhimurium during heating at rising temperatures. Letters in Applied Microbiology. 4: 13-16.
  - 114. Mackey, B. M. and Derrick, C. M. 1986b. Elevation of the heat resistance of Salmonella typhimurium by sublethal heat shock. Journal of applied Bacteriology. 61: 389-93.

115. Marth, E.H. 1998. Extended shelf life refrigerated foods: microbiological quality and safety. Food Technology, 52(2): 57-62.

33.19 March 1966 1866

116. McCardell, B. A., Madden, J. M. and Lee, E. C. 1984. Campylobacter jejuni and Campylobacter coli production of a cytotonic toxin immunotogically similar to cholera toxin. Journal of Food Protection 47:943-949.

Statement of the William

- 117. McCardell, B. A., Madden, J. M. and Stanfield, J. T. 1986. Effect of iron concentration on toxin production in Campylobacter jejuni and Campylobacter coli, Canadian Journal of Microbiology. 32: 395-401.
- 118. McCullough, N. B. and Eisele, C. W. 1951. Experimental human salmonellosis: pathogenicity of strains of Salmonella newport, Salmonella derby and Salmonella bareilly obtained from spray-dried whole egg. Journal of Infectious Diseases 89: 209-213.
- 119. McDade, J. H. and Hall, L. B. 1964. Survival of Gram-negative bacteria in the environment. J. Effect of relative humidity on surface exposed organisms.

  American Journal of Hygiene. 80: 192-204.
- 120. McMeekin, T. A. and Thomas, C.J. 1978. Retention of bacteria on chicken skin after immersion in bacterial suspensions. *J. Appl. Bacteriol.* 45: 383-387.
- 121. McMeekin, T. A. and Thomas C. J. 1979. Aspects of microbial ecology of poultry processing and storage: a rewiew. Food Technology in Australia, 31: 35-43.
- 122. Mead, G. C. 1989 Hygiene Problems and Control Process contamination. *In* Processing of Poultry, ed. Mead, G. C. Elsevier Applied Science, London, 183-220.

don the the continues of the continues to be a finished

Straight Bulletin

- Mead, G. C.1982. Microbiology of poultry and game birds. In Meat Microbiology, ed. Brown, M. H.. Applied Science Publishers, London, 67-101.
  - 124. Moats, W. A., Dabbah, R. and Edwards, V. M. 1971. Interpretation of nonlogarithmic survivor curves of heated bacteria. *Journal of Food Science*. 36: 523-6.
- Monk, J. D., Beuchat, L.R., and Doyle, M.P. 1995. Irradiation inactivation of food-borne microorganisms. *J. Food Protection*. 58(2): 197-208.

The the second of the

126. Morgan, A. I., Radewonuk, E.R., and Scullen, O.J. 1996. Ultra High Temperature Short Time Surface Pasteurization of Meat. *J. Food Sci.* 61(6): 1216-1218

127. Morrison, G. J., and Fleet, G.H. 1985. Reduction of *Salmonella* on chicken carcasses by immersion treatments. *J. Food Protection*. 48(11): 939-943.

CONTRACTOR OF THE SECOND SECURITION OF THE SECOND OF THE S

- Mountney, G. J. and O'Malley, J. 1965. Acids as poultry meat preservatives. Poultry Sci. 44: 582-588.
- 129. Mulder, R.W. and Bolder, N.M. 1984. Methods to reduce Salmonella contamination during processing of poultry, p. 242-248. In G. H. Snoyenbos (ed.) Proc. Int. Symp. Salmonella. American Association of Avian Pathologists, Inc. University of Pennsylvania, Bew Bolton Center, Kennett Square, PA.
- 130. Mulder, R.W., Notermans, S and Kampelmacher, E.H. 1977. Inactivation of salmonellae on chilled and deep frozen broiler carcasses by irradiation. *J. Appl. Bacteriol.* 42: 179-185.
- 131. Mulder, R. W., van der Hulst, M.C., and Bolder, N.M., 1987. Research not: Salmonella decontamination of broiler carcasses with lactic acid, L-cystein, and hydrogen peroxide. *Poult. Sci.* 66: 1555-1557.
  - 132. Murdock, D. I. 1950. Inhibitory action of citric acid on tomato juice flat-sour organisms. *Food Res.* 15: 107.

- 133. Muriana, P.M. 1996. Bacteriocins for control of *Listeria* spp. in food. *J. Food*
- 134. Notermans, S. and Kampelmacher, E. H. 1974. Attachment of some bacterial strains to the skin of broiler chickens. *Br. Poultry Sci.* 15: 573-585.
- 135. Olson, J. C., Jr. and Nottingham, P. M. 1980. In "Microbial Ecology of Foods, vol.1," Factors affecting life and death of microorganisms, ed. International Commission on Microbiological Specifications of Foods, p.1, Academic Press, Inc., New York.
  - 136. Packman, E. W., Abbott, D. D., and Harrisson, J. W. E. 1963. Comparative subacute toxicity for rabbits of citric, fumaric and tartaric acids. *Toxicol Appl. Pharmacol.* 5: 163.
  - 137. Patterson, J. T. and Gibbs, P. A. 1977. Incidence and sources of Enterobacteriaceae found on frozen broilers. *In* The Quality of Poultry Meat (Ed. S. Scholtyssek), Proceedings of the Third European Symposium on Poultry Meat Quality, Grub, W. Germany, Eugen Ulmer GmbH & Co., Stuttgart, pp. 69-76.

- 138. Pearson, A. M. and Gillett, T. A. 1996. *Processed Meats*, 3<sup>rd</sup> Edition. Chapman and Hall.
- 139. Penner, J. L. 1988. The genus *Campylobacter*: a decade of progress. *Clinical Microbiology Reviews* 1:157-72.
- 140. Pether, J. V. S. and Gilbert, R. J. 1971. The survival of *Salmonella* on fingertips and transfer of the organisms to foods. *Journal of Hygiene* 69:673-681.
- 141. Poysky, F. T., Paranjpye, R.N., Peterson, M.E. Pelroy, G.A. Guttman, A.E., and Eklund, M.W. 1997. Inactivation of *Listeria monocytogenes* on hot-smoked salmon by the interaction of heat and smoke or liquid smoke. *J. Food Protection*. 60(6): 649-654.
- Put, H. M. and Aalbergsberg, W. I. J. 1967. Occurrence of *Bacillus subtilis* with high heat resistance. *Journal of Applied Bacteriology*, 30: 411–419.
  - 143. Prepared Foods. 1988. Poultry processor predicts product perishability. *Prepared Foods* 157:118.

to the first of the company of the second second second

- 144. Raffalli, J., Rosec, J.P., Carlez, A., Dumay, E., Richard, N., and Cheftel J.C. 1994. High pressure stress and inactivation of *Listeria innocua* in inoculated dairy cream. *Sci. Alim.* 14: 349-358.
- 145. Rammell, C. G. 1962. Inhibition by citrate of the growth of coagulase-positive staphylococci. J. Bacterriol. 84: 1123-1128.

No. 18 Comments

date in the tra

- 146. Reiss, J. 1976. Prevention of the formation of mycotoxins in whole wheat bread by citric and lactic acids. *Experimentia*. 32: 168-175.
- 147. Rengel, A. and Mendoza, S. 1984. Isolation of Salmonella from raw chicken in Venezuela. J. Food Protection. 47(3): 213-216.

antiglian realization and the control of the contro

148. Resurreccion, A. V. A., Galvez, F.C.F., Fletcher, S.M., and Misra, S.K. 1995. Consumer attitudes toward irradiated food: result of a new study. *J. Food Protection*. 58(2): 193-196.

AND COMMERCIAL SECTION OF THE SECTIO

149. Reynolds, A. E. and Carpenter, J. A. 1974. *J. Anim. Sci.* 38 : 515-519.

10 May 19 44

- 150. Robach, M. C. 1980. Use of preservatives to control microorganisms in food. *Food Technol.* 34(10): 81-87.
- 151. Robach, M. C. and Sofos, J. H. 1982. Use of sorbates in meat products, fresh poultry and poultry products: A review. *J. Food Prot.* 45: 374-383.

152. Roberts, T. 1993. Cost of food borne illness and preventive int rventions, p. 514-518. In Proceedings of the 1993 Public Health Conference on Records and Statistics. Toward the Year 2000 - Refining the Measures. U.S. Dept. Of Health and Human Services, Washington, D.C.

Spring in white within

- 153. Roberts, T. A., Baird-Parker, A. C., and Tompkin, A. C. (Eds.). 1996. "Microorganisms in Foods, vol.5. Microbiological Specifications of Food Pathogens," p. 513. Blackie Academic and Professional, London.
- 154. Robinson, D. A. 1981. Infective dose of Campylobacter jejuni in milk. British Medical Journal. 282: 1584-1587.
- Rodriguez, A. C., Smerage, G. H., Teixeira, A. A., Lindsay, J. A. and Busta, F. F. 1991. Population model of bacterial spores for validation of dynamic thermal processes. *Journal of Food Process Engineering*. 15: 1-30.
- 156. Rodriguez, A.C., Ledesma, A.M., Riemann, H.P., and Farver, T.B. 1996. Short-term treatment with alkali and/or hot water to remove common pathogenic and spoilage bacteria from chicken wing skin. J. Food Protection. 59(7): 746-750
- 157. Root, W. 1980. Food. Simon and Schuster, New York, NY.

The state of the s

eli california i di propio di una comita di la comita di una constituzioni di contra di la comita di Registi

1.

- 158. Rosenficid, J. A., Arnold, G. A., Davey, G. R., Archer, R. S. and Woods, W. H. 1985. Serotyping of Campylobacter jejuni from an outbreak of enteritis implicating chicken, Journal of Infections. 1: 159-165.
- 159. Russell, S. M. 1997. A Rapid Method for Predicting the Potential Shelf Life of Fresh Broiler Chicken Carcasses. *J. Food Protection*. 60(2):148-152.

the fact of the contract of th

- 160. Sala, A. 1986. "Radiant properties of materials." Elsevier, Amsterdam.
- 161. Salmon, D. E. and Smith, T. 1885. Report on swine plague, 2nd Annual Report, Washington DC: US Department of Agriculture, Bureau of Animal Industries: 184-246:
  - 162. Sams, A.R. and Feria, R. 1991. Microbial Effects of Ultrasonication of Broiler Drumsticks Skin. *J. Food Science*. 56(1): 247-248.
- 163. Sapru, V., Teixeira, A. A., Smerage, G. H. and Lindsay, J. A. 1992.

  Predicting thermophilic spore population dynamics for UHT sterilization processes. *Journal of Food Science* 57: 1248-1257.
- 164. Sapru, V., Smerage, G. H., Teixeira, A. A. and Lindsay, J. A. 1993. Comparison of predictive models for bacterial spore population responses t sterilization temperatures. *Journal of Food Science*. 58: 223-228.

165. Shane, S. M. 1988. Update on the fate of irradiation. Poultry Proc. 4: 48-57.

the second second

Shane, S. M. 1992. The significance of Campylobacter jejuni infection in 166. poultry - A review. Avian Pathol. 21: 189-213.

- Shefet, S. M., Sheldon, B.W., and Klaenhammer, T.R. 1995. Efficacy of **167.** optimized nisin-based treatments to inhibit Salmonella typhimurium and extend shelf life of broiler carcasses. J. Food Protection. 58: 1077-1082
- Sheldon, B. W. and Brown, A. L. 1986. Efficacy of ozone as a disinfectant 168. for poultry carcasses and chill water. J. Food Sci. 51: 305-309.
- Shull, J. J., Cargo, G. T. and Ernst, R. R. 1963. Kinetics of heat activation of 169. thermal death of bacterial spores. Applied Microbiology. 11, 485-487.
- Siegel, R. and Howell, J. R. 1992. "Thermal radiation heat transfer." 170. Hemisphere, New York.
- Silliker, J. H. 1982. The Salmonella problem: Current status and future 171. direction. J. Food Prot. 45: 661-666. Security of the Company of the Compa
- Silliker, J. H. and Wolfe, S. K. 1980. Microbiological safety considerations in *172*: controlled-atmosphere storage of meats. Food Technology 74:59-63.
- 173. Simonsen, B. 1989. Microbiological criteria for poultry products. In Processing of Poultry, ed. G. C. Mead. Elsevier Science Publishers Ltd., London.

on a grif of metals and governments and provide the

alternative and the control of the c

....

- 174. Sims, J. E., Kelley, D. C. and Foltz, V. D. 1969. Effects of time and temperature on salmonellae in inoculated butter, Journal of Milk and Food Technology 32:485-488.
- Sinha, D. P., Drury, A. R., and Conner, G. H. 1968. The in vitro effect of citric acid and sodium citrate on Streptococcus agalactiae in milk. Indian Vet. J. 45: 805-811.
- 176. Slavik, M. F., Kim, J., and Walker, J.T. 1994. Reduction of Salmonella and Campylobacter on Chicken Carcasses by Changing Scalding Temperature. J. Food Protection. 58(6): 689-691.
- Skirrow, M. B. 1982. Campylobacter enteritis the first five years. Journal of 177. Hygiene (Cambridge) 89:84.
- Skirrow, M. B. 1991. Epidemiology of Campyiobacter enteritis. International 178. Journal of Food Microbiology 12: 9-16.

179. Smith J. L. 1995. Arthritis, Guillain-Barre Syndrome, and other sequelae of Campylobacter jejuni enteritis. J. of Food Protection. 58(10): 1153-1170.

No compare weeks with SEED Co. Co.

The second of th

- 180. Smith, J. L., Palumbo, S. A. and Walls, L. 1993. Relationships between food-borne bacterial pathogens and reactive arthritides. *Journal of Food Safety* 13:209-236.
- 181. Speck, M. L. (ed.) 1984. Compendium of methods for the Microbiological Examination of foods (2nd ed.), Washington, DC: American Public Health Association.
- 182. Sofos, J.N. (1994). Microbial growth and its control in meat, poultry and fish. In Quality attributes and their measurments in meat, poultry, and fish products. Ed. Pearson, A. M. and Dutson, T. R. Chapman & Hall, London, 359-403.
- 183. Stadelman, W. J., Olson, V. M., Shemwell, G. A. and Rasch, S. 1988. Egg and Poultry-meat Processing. Ellis Horwood, England.

THE COURT OF THE PERSON OF THE

184. Stermer, R. A., Lasater-Smith, M., and Brasington, C.F. 1987. Ultraviolet radiation - An effective bactericide for fresh meat. *J. Food Prot.* 50(2): 108-111.

The transplant of the control of the

31、10克拉克、基定的

the for the second through the second

- Stern, N. J. 1992. Reservoirs for *Campylobacter jejuni* and approaches for intervention in poultry, p.49-60. *In I.* Nachamkin, M. J. Blaser, and L. S. Tompkins (ed.), *Campylobacter jejuni*, current status and future trends. American Society for Microbiology, Washington, D. C.
- Stem, N.J., Rothenberg, P.J. and Stone, J.M. 1985. Enumeration and Reduction of Campylobacter jejuni in Poultry and Red Meats. J. Food Protection. 48(7): 606-610.
- 187. Stumbo, C. R. 1973. *Thermobacteriology in Food Processing*. 2nd edn.

  Academic Press, New York.
  - 188. Subramanian, C. S. and Marth, E. H. 1968. Multiplication of Salmonella typhimunum in skim milk with and without added hydrochloric, lactic and citric acids. J. Milk Food Technol. 31: 323-326.
  - 189. Sugarman, C. 1992. USDA approves disinfection method. Washington Post, October 14, A12.
  - 190. Surkiewicz, B. F., Johnston, R. W., Moran, A. B., and Krumm, G. W. 1969. A bacteriological survey of chicken eviscerating plants. *Food Technol.* 23: 80-87.

- 191. Tamblyn, K. C., and Conner, D.E. 1997. Bactericidal activity of organic acids against Salmonella typhimunium attached to broiler chicken skin. J. Food Protection. 60(6): 629-633.
- Tamminga, S. K., Bcumer, R. R., Kampelmacher, E. H. and van Lcusden, F. M. 1977. Survival of Salmonella eastbourne and Salmonella typhimurium in milk chocolate prepared with artificially contaminated milk powder. Journal of Hygiene 79: 333-337.
- Tauxe, R. V. 1992. Epidemiology of Campylobacter jejuni infections in the United States and other industrialized nations, p. 9-19. *In I. Nachamkin, M. J. Blaser, and L. S. Tompkins (ed.), Campylobacter jejuni: current status and future trends.* American Society for Microbiology, Washington, D. C.
- 194. Teo, Y., Raynor, T.J., Ellajosyula, K.R., and Knabel, S.J. 1996. Synergistic Effect of High Temperature and High pH on the Destruction of Salmonella enteritidis and Escherichia coli O157:H7. Journal of Food Protection. 59(10): 1023-1030.
- Thayer, D. W., Dickerson, C. Y., Rao, D. R., Boyd, G., and Chawan, C. B. 1992. Destruction of Salmonella typhimunum on chicken wings by Gamma Radiation. J. Of Food Science, 57(3): 586-592.
- 196. Thiessen, G. P., Usborne, W. R., and Orr, H. L. 1983. The efficacy of chlorine dioxide in controlling Salmonella contamination and its effect on product quality of chicken broiler carcasses. *Poult. Sci.* 63: 647-653.
- Thomas, C. J. and McMeekin, T.A. 1980. Contamination of broiler carcass skin during commercial processing procedures: an electron microscopic study. *Appl. Environ. Microbiol.* 40: 133-144.
- 198: Thomas, C. J. and McMeekin, T.A. 1982. Attachment of Salmonella spp. to chicken muscle surfaces. Appl. Environ. Micribiol. 42: 130-134.
- 199. Thomas, C. J. and McMeekin, T.A., 1984. Effect of water uptake by poultry tissues on contamination by bacteria during immersion in bacterial suspensions. *J. Food Prot.* 47: 398-402.
- 200. Thomas, C. J., McMeekin, T.A., and Patterson, J.T. 1987. Prevention of microbial contamination in the poultry processing plant. pp. 163-179. In F. J. A. Smulders (ed.). Elimination of Pathogenic Organisms from Meat and Poultry. Elsevier Science Publishers, Amsterdam.

医环状性 医二氏性神经病性病

group filter and the contribution of a growing file object to a grow that

Thomson, J. E., Banwart, G.J., Sanders, D.H., and Mercuri, A.J. 1967. Effect 201. of chlorine, antibiotics, beta-propiolactone, acids, and washing on Salmonella typhimurium on eviscerated fryer chickens. Poultry Sci. 46: 146-150. 

如此 医性温度性 建酸硫酸钾 烷

- Thomson, J. E., Cox, N. A., and Bailey, J. S. 1977. Control of Salmonella and 202. extension of shelf life of broiler carcasses with a glutarraldehyde product. J. Food Science. 42: 1352-1355.
- Todd, E. C. D. 1980. Poultry-associated food-borne disease its occurrence. 203. cost, source, and prevention. J. Milk and Food Technol. 43: 129-139.

Signal Contactions Secret

41944 BAN LY MAKE IN

- Toledo, R.T. 1993. Fundamentals of food process engineering. 2<sup>nd</sup> edition. 204. Chapman and Hall, New York, NY.
- Tsai, L. S., Schade, J.E., and Molyneux, B.T. 1991. Chlorination of poultry 205. chiller water. Chlorine demand and disinfection efficacy. Poultry Sci. 74: 188-
- USDA. 1994. The Livestock and Meat Situation. U. S. Department of 206. Agriculture, Washington, D. C. and the state of the said of t

and the transfer of the second of the second

- USDA: 1994a. Acceptable antimicrobial treatments. Food Safety and 207. Inspection Service Notice 49-94, Dec 21, FSIS, Washington D. C.
- 208. Villareal M. E., Baker, R. C., and Regenstein, J. M. 1990 The incidence of Salmonella on poultry carcasses following the use of slow release chlorine dioxide (Alcide). J. Food Protection: 53(6): 465-467
- 209. Walker, H. W. and Ayres, J. C. 1959. Microorganisms associated with commercially processed turkeys. Poultry Science. 38: 1351-1355. (基)的复数 (10 等) 医2000 (34) (20 day) (10 ) 电表层数字
  - Walker, R. I., Caldwell, M. B., Lee, E. C., Geffen, P., Trust, T. J. and Ruiz-210. Palacios, G. M. 1986. Pathophysiology of Campyiobacter enteritis. Microbiological Reviews 50: 81-94.
- 211. Wang, D. I., Scharer, J. and Humphrey, A. E. 1964. Kinetic of death of bacterial spores at elevated temperatures. Applied Microbiology, 12: 451of 100% (150). The Cartel Basel of the Males extrem 454.
- Wang, W., Powers, B. W.: Luechtefeld, N. W. and Blaser, M. J. 1983. 212. Effects of disinfectants on Campylobacter jejuni. Applied and Environmental Microbiology 45:1202-1205.
- Yokotani, H., Usui, T., Nakaguchi, T., Kanabayashi, T., Tanda, M., and 213. Aramaki, Y. 1971. Acute and subacute toxilogical studies of TAKEDA-citric acid in mice and rats. J. Takeda Res. Lab. 30: 35.

and the second of the

- 214. Yousef, A.E. 1996. Pulsed light and pulsed electric fields for cold-pasteurization of foods. Presented at th Annual Meeting of the Food Research Institute, University of Wisconsin, Madison, May 30.
- Zeitoun, A. A. M., and Debevere, J. M. 1980. Inhibition, survival and growth of Listeria monocytogenes on poultry as influenced by buffered lactic acid treatment and modified atmosphere packaging. *Int. J. Food Microbiol.* 14:

where the position for the entries of both the entries of the property of the experience of the entries of

## CHAPTER 3

and 1986年 1987年 1986年 1986年

# INACTIVATION OF MICROFLORA ON WHOLE BROILER CARCASSES BY RADIANT HEAT AND ANTIMICROBIAL ADDITIVES!

<sup>&</sup>lt;sup>1</sup>Islam, M. M., and Toledo, R. T. To be submitted to the Journal of Food Science.

#### **ABSTRACT**

The capability of radiant heat to reduce resident microflora on whole-broilers was investigated. Whole ready-to-cook broilers were exposed to a radiant wall (RW) at 649 °C, for 0, 3, 4, 5, or 8 s or dipped in a solution containing 1% buffered sodium citrate, pH 5.8 (BSC), 0.5% citric acid (CA) or 2% liquid smoke (LS) prior to RW exposure. Radiant heating in an air (RW/A) or superheated steam atmosphere (RW/S) was also tested. RW/S treatment for 5 s reduced total plate count (TPC) by 1.23 to 1.73 log. RW exposure for 3 and 4 s showed less than a log reduction. RW exposure for 8 s resulted in 2.12 to 2.41 log reduction of TPC however, product exhibited a cooked skin. TPC reduction was not significantly different with RW/A and RW/S treatments but skin in RW/A treatments appeared to be dehydrated. Dipping in 1% BSC was synergistic with RW in reducing the TPC but CA and LS pre-treatments had no effect. Orientation during RW treatment showed no significant differences on TPC. The inside body cavity of treated carcasses was not affected by the RW treatment

KEY WORDS: Poultry, microorganisms, pasteurization, radiant heat; sodium

AND THE STATE OF T

Carry Marchael Control of the Contro

manada wakan a sanagarian ili kambada are mara kabili na agas kabili kabili kabili kabili kabili kabili kabili

raktigati. Malabi oleh Sona oleh Sona kendilari bilan di berandan dalah bilan beranda bilan bilan beranda bera

radio spirito etta este a detare escribir. Si que diferir il distrato ancatata de estrata anticata de esta de e

antitati kata mana ili katan na ara ara ang mangan na arawa ili kang mangan ng masakiki

#### INTRODUCTION

In 1992, the U.S. poultry industry produced \$ 12 billion worth of birds at the farm level, which were processed into products valued at \$32 billion (Durham: 1993). In 1993, over 27.6 billion pounds of ready-to-eat poultry products were produced (Agricultural Statistics Board, USDA, 1994). The widespread sale and use of raw chicken demands closer attention to their microbiology. Chilled or frozen, chicken may be marketed as whole whole cutup, bone-in parts or deboned. With few exceptions, bacterial growth is a surface phenomenon in raw poultry products. The quality of the chicken meat is considered optimum immediately after processing, and maintenance of acceptable quality depends on initial microbial levels and measures taken t minimize the growth of organisms. The surface micro flora of ready-to-eat chicken carcasses is heterogeneous, consisting of mesophilic and psychrotrophic bacteria from the animal itself, soil and water bacteria from the environment, and bacterial species introduced by man and equipment during processing (Grau, 1986; ICMSF(1980). Populations of bacteria on surfaces of raw chicken carcasses at the end of processing vary, but typically the range is from 103 to 105 aerobic mesophillic organisms per inch² (ICMSF) 1980). Because the postprocessing environment is frequently refrigerated, a low-level contamination with psychrotrophic bacteria almost always occurs. The two major concerns are control of spoilage organisms which cause consumers to reject the product due to unacceptable odor or flavor, and minimization of pathogenic organisms which may, under prolonged storage or faulty handling, lead to a health hazard (Cunningham, 1987). When chicken is held under refrigeration, the micro flora begins to shift toward psychrotrophs of the Pseudomonas-AcinetobacterMoraxella group (Barnes, 1976). Earlier studies by Barnes and Impey (1969) found that the organisms most commonly found growing on poultry carcasses at low temperatures (around 1°C) were pigmented and non-pigmented species of Pseudomonas, Pseudomonas putrifaciens, and strains of Acinetobacter. These authors also noted that P. putrifaciens grew much faster on leg muscle than on breast, and explained this on the basis of a difference in pH - leg muscle having pH 6.4 - 6.7, and breast 5.7 - 5.9. In an earlier report (Ayres 1959), it was stated that the microbial population responsible for spoilage of the refrigerated product (4°C) was psychrotrophic. After 12 days storage, the dominant psychrotrophic population was 90% Pseudomonas-Achromobacter. Pseudomonads were the most significant Gram negative rods associated with spoilage of poultry.

Poultry processors must minimize microbial counts in processed birds to prolong shelf life as well as reduce the incidence of pathogenic microorganisms. Generally, practices used to reduce microbial counts would also reduce pathogenic microorganisms. It was hypothesized that very rapid surface heating for a short time would effectively reduce the number of microorganisms on the surface while maintaining the normal raw appearance of the product. Surface decontamination may be useful because pathogenic microorganisms are usually only on the broiler surface (Gill and Penney, 1977). Generally, microbial inactivation requires less energy than cooking (Harper, 1976), therefore, radiant heat of adequate intensity to only heat the surface would be effective for this purpose. High intensity radiant heat application was tested using a Radiant Wall Oven (RWO). The system consists of a cylindrical steel alloy (91 cm long by 45.7 cm internal diameter) enclosed by a larger cylinder which is insulated on the outside. A jet gas burner forces combustion gases in the annular space between

the cylinders generating intense heat to raise the temperature of the inside cylinder sufficiently high to make the surface an intense radiant h at source. The oven controls the surface temperature of the radiant wall, this being the only true manifestation of the radiant heat transfer. When steam is introduced into the radiant wall, the high temperature converts saturated steam rapidly into superheated steam. Thus, heating may be done in an atmosphere of saturated steam (RW/S) or if the steam is not used, an air atmosphere surrounds th sample (RW/A).

The objective of this study were: to define the heating parameters for decontamination of whole dressed broilers additives without producing a cooked appearance on the surface using radiant heat and to investigate the synergy of the thermal treatment and various antimicrobial additives on inactivation of indigenous microorganisms on the chicken skin.

#### MATERIALS & METHODS

The Control of the Co

#### Whole broiler chickens

Forty whole broiler carcasses in each of three replicate trials (120 total) were obtained directly from the chiller exit of a commercial broiler processing plant. These carcasses were processed from 7 - 8 weeks old birds and semi-scalded at 60°C for 90 s. The broiler carcasses were transported in ice to the laboratory where they were placed in a walk-in cooler at 0.5°C and treated within 2 h.

#### Radiant energy source

A radiant wall (RW) oven (Model 12-36, Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA) was used. Samples were exposed to

the radiant wall while travelling on a wire conveyor belt through the central axis of the heated cylinder. A special rack was constructed to permit the carcasses to ride the conveyor vertically with the vent cavity positioned downwards. Most carcasses entered the RW with the breast forward. To determine if the orientation had an effect, a set of samples were treated with entering the RW oven with the back forward. The carcasses were surrounded by the radiant wall, thus all surfaces received equal exposure to the radiant heat. The linear speed of the conveyor belt was adjusted to achieve a desired dwell time in the radiant zone.

#### Antimicrobial agents

Buffered sodium citrate, pH 5.8 (BSC) is a USDA approved ingredient for meats provided by WTI, Inc (Highland, NY). Food grade citric acid (CA) was obtained from Greenfield-Thorpe Corp. (Chicago IL). Liquid smoke (LS) was a specially formulated wood smoke fraction designated "Code V" (Hickory Specialties, Brentwood, TN). Aqueous solutions of these materials were prepared and placed in a 4-liter stainless steel beaker to permit complete immersion of a whole carcass in the solution. The solution was replaced with each carcass. Solutions were 1% BSC, 0.5% CA w/w or 2% LS (v/v). These materials have been found in our preliminary work to have some antimicrobial effects.

Treatments: Whole carcasses were taken directly from the cold room and either introduced directly into the RW oven or dipped in the antimicrobial solution at ambient temperature (24 - 27°C) for 1 min. followed by RW exposure. Following the RW treatment, each carcass was removed from the conveyor and placed in a sterile Stomacher bag (Seward Medical, UK), overwrapped with a 1-mil

polyethylene bag and stored in the walk-in cooler at 0.5°C until analyzed. RW temperature was maintained at 649°C for all treatments. Exposure time was 3, 4, 5, or 8 s and the atmosphere was either air or superheated steam. The experimental design (replicate x time of RW exposure x no. of dip treatments and RW atmosphere) was 3 x 5 x 8. The 8 dip RW atmosphere treatments were as follows: No dip steam RW atmosphere (RW/S/0); No dip air RW atmosphere (RW/A/0); BSC dip steam RW atmosphere (RW/S/BSC); BSC dip air RW atmosphere (RW/A/BSC); CA dip steam RW atmosphere (RW/S/CA), CA dip air RW atmosphere (RW/A/CA; LS dip steam RW atmosphere (RW/S/LS) and LS dip air RW atmosphere (RW/A/LS). One carcass was used for each of 3 replicates for a total of 120 carcasses treated.

Sampling and CFU enumeration: Carcasses were visually evaluated by the authors after RW exposure for discoloration caused by burning, cooking or interaction by heat and the pre-dip solutions. Samples exhibiting changes in appearance from the raw carcasses were considered unacceptable treatments. Following microbiological sampling, the carcasses were baked and the cooked product evaluated for off-flavors from the dip and RW treatments. Colony forming units (CFU) were enumerated on chicken skin by excising aseptically about 2.5 g (1 sq. inch of skin ) each from 3 different areas (breast, back and vent) of each carcass. The excised tissue was placed in a Stomacher bag (Seward Medical, London) containing 97.5 ml of sterile 0.1% bacto peptone solution (Difco Laboratories, Detroit, MI) and pummeled for 60 s in a Model 400 Stomacher (Seward Medical, London). Serial dilutions were made with sterile 0.1 % bactopeptone. A 2.5 g tissue sample was scrapped from the middle of the inside carcass cavity and similarly prepared for microbial evaluation. The Total Plate

Count (TPC) procedure described by Swanson et al. (1992) was used. Pour plates were made using standard Plate Count Agar (Difco Laboratories) and plates were incubated at 32°C for 24 - 48 h. Colony forming units (CFU) were counted using a Quebec dark field colony counter (American Optical Company, Buffalo, NY):

Statistical analyses :Microbiological data were transformed into logarithms of the number of colony-forming units/cm2 ( $log_{10}/cm2$ ). Average data and standard errors were calculated from three replications. The analysis of variance (ANOVA) procedure was used to detect significance of replications, exposure times, dip treatments, orientation of chicken and different atmospheres. Comparisons of means were based on Duncan's multiple range test. All values reported as significant were analyzed at the  $\alpha = 0.05$  level.

#### **RESULTS AND DISCUSSION**

Effect of treatment time: The efficacy of the different treatments in decontaminating fresh chicken broilers is presented in Table 1. As expected, increased reduction of surface microorganisms resulted with increasing treatment time. However, although samples treated for 8 sec; consistently reduced surface flora by at least 2 log, visual evaluation of the samples showed a cooked appearance. On the other hand, treatment times of 3 and 4 s failed to consistently reduce TPC by 1 log. Broilers dipped in 1% BSC solution before RW exposure for 3 or 4 sec without steam showed more than 1 log reduction in TPC. The result is due to combined effects of the antimicrobial agent and radiant heat. RW exposure for 5 s consistently resulted in 1.26 to 1.73 log TPC reduction. At the time of experiment, the RW burner was inadequate to heat the

RW to a higher temperature and thus, the effects of a more intense radiant heat treatment could not be evaluated at this time. We hypothesiged that a higher RW temperature will achieve greater TPC reduction with shorter treatment time and not induce visible change in product appearance.

Effect of steam: A superheated steam atmosphere in the RW oven did not affect TPC reduction on RW exposure. Microbial log reductions on samples treated in an air atmosphere were not significantly different from log reductions on samples treated in a superheated steam atmosphere, as shown in Fig.1. Steam was expected to modulate the harshness of dry radiant heat on the delicate chicken skin to avoid burning at any given spot. We observed that when steam was used, the broiler skin appeared moist and fresh after RW exposure. However, as indicated in the graph, a steam atmosphere reduced slightly the radiant heat effect on the microorganisms probably because of the lower transmittance of the radiant energy through steam compared to air. Although using steam or air atmosphere had no significant effect on TPC reduction, use of a steam atmosphere in the RW oven is still desirable because of a better appearance of the treated carcasses in a steam atmosphere.

Effect of anti-microbial agents: TPC and log reduction data for various pretreatments by anti-microbial preservatives are presented in Table 1. At the concentrations of the 3 anti-microbial agents used, only a slight synergistic effect on TPC reduction over RW treatment alone was observed. While BSC dip improved the reduction by about half a log, both citric acid and liquid smoke treatments improved it only by a quarter log. In an earlier experiment we determined that retention of BSC by chicken dipped in BSC solution is only approximately 1% of the solution concentration. Thus, a 1% BSC solution would permit retention of only a 0.01% BSC on the chicken surface. Thus, higher concentrations than 1% BSC could possibly b used to get a better synergistic effect on microbial decontamination.

Effect of carcass position: Table 2 shows that there was no significant difference in total reduction of microorganisms due to orientation of carcasses. There was also, no significant difference in log counts of microorganisms inside the body cavity of chicken carcasses before and after the radiant heat treatment (Table 3). This indicates that the radiant heat did not reach the inside body cavity of the carcasses and could not bring any reduction of TPC.

#### CONCLUSION.

Radiant heat from a high temperatrure radiant wall induced microbicidal effects on surfaces of whole broilers without cooking the surface. Radiant wall exposure for 5 s at 649 °C with a 1 min predip in 1 % buffered sodium citrate solution induced more than 1.5 log reduction in TPC.

The Control of Arrest in Landing Land Control of Spire of the Effective States

《安徽·福州·西州通报》(1994年) [1] 1、 第二次2000年 (1916年 [1916年 - 1918年 [1918年 - 1918年 - 1918年 - 1918年 - 1918年 - 1918年 - 1918年

Control of the second of the s

ting of the second of the seco

our our care comment side was a factor of the comment of the comme

der palar i fill behätelse for ignal är samt blort i fill at et i brigger ål, filmfål, eftert j

The Park the most of the control of the first the control of the c

androuser and the second of the second of the second region of the analysis of the second second second second

#### REFERENCES

. .

- Agricultural Statistics Board. 1994. Poultry slaughter: April, p. 21-22. NASS. USDA.
- Ayres, J. C.. 1959. Effect of sanitation, packaging and antibiotics on the microbial spoilage of commercially processed poultry. Iowa State J. Sci. 34:27
- Bailey, J. S., Cox, N. A., and Blankenship, L. C. 1990. Persistence and spread of external Salmonella during broiler production. Poultry Sci., 69:154
- Barnes, E.M. 1960. Sources of different psychrophilic spoilage organisms on chilled eviscerated poultry. Proceedings of the Tenth International Congress of Refrigeration, Copenhagen, 3:97
- Barnes, E.M. 1976. Microbiological problems of poultry at refrigerator temperatures a review. J. Sci. of Food and Agriculture, 27:777.
- Barnes, E.M. and Impey, C.S. 1969. Psychrophilic spoilage bacteria of poultry. J. Appl. Bacteriol. 31:97
- Barnes, E.M., and Thornley, M.J. 1966. The spoilage flora of eviscerated chickens stored at different temperatures. J. of Food Technol., 1:113.

· 医痛性 计编码线像形式 计分词形式 化二

- Durham, D. 1993. Food cost review, 1992. Report #672.36.USDA.
- Gill, C.O. and Penney, N. 1977. Penetration of bacteria into meat. Appl. Environ. Microbiol 33:1284.
- Harper, J.C. 1976. Chap.12. In "Elements of Food Engineering," AVI Press, Westport, Connecticut.
- Lillard, H.S. 1990. Impact of commercial processing procedures on bacterial contamination of broiler carcasses. J. Food Protect. 53:202.
- Lillard, H.S. 1994. Effect of TSP on Salmonellae attached to chicken skin. J. Food Protect. 57:465.
- Lillard, H.S., Blankenship, L. C., Dickens, J. A., Craven, S. E., and Shackelford, A. D. 1987. Effect of acetic acid on the microbiological quality of scalded picked and unpicked broiler carcasses. J. Food Protect. 50:112.
- McMeekin, T.A. and Thomas C. J. 1979 Aspects of microbial ecology of poultry processing and storage: a review. Food Technol. in Australia, 31: 35.

- Patterson, J.T. and Gibbs, P.A 1977. Incidence and sources of Enterobacteriaceae found on frozen broilers. In "The Quality of Poultry Meat," (Ed. S. Scholtyssek), Proceedings of the Third European Symposium on Poultry Meat Quality, Grub, W. Germany, Eugen Ulmer GmbH & Co., Stuttgart, pp. 69-76.
- Simonsen, B. 1989. Microbiological criteria for poultry products. In "Processing of Poultry," (ed.) G.C. Mead. Elsevier Science Publishers Ltd., London.

Sales Company of the Edition

- Swanson, K.M.J., Busta, F.F., Peterson, E.H., and Johnson, M.G. 1992. Colony count methods, p. 75-95. In "Compendium of methods for the microbiological examination of foods," 3<sup>rd</sup> Edition. C. Vanderzant and D. F. Splittstoesser (ed.), American Public Health Association, Washington, D. C.
- Walker, H.W. and Ayres, J.C. 1959. Microorganisms associated with commercially processed turkeys. Poultry Sci., 38:1351.

2006年 1965年 (Prof. ) - 1966年 (1966年) 1866年 (1966年) - 1966年 (1966年) 1966年 (1966年) 1966年 (1966年) 1966年 (1966年)

and Agent and African College (1) for the Agent Andrews (1) and Andrews (1) an

AND AND THE PART OF MADE AND ARREST

他们的人,如此就是<sup>我们</sup>成了一个人,也是我们还有什么

one of the engineering of the section of the sectio

and he has the street of the three of materials from the state of the

The feet of the feet of the second of the second section of the section of the

and the first of the second of

4. 或减失处计

TABLE 1: Mean ± standard error of log numbers of aerobic bacteria on the surface of fresh broilers variously treated and exposed to radiant heat for different periods of time

Some of the second second

New York Control	Mean ± SE <sup>a</sup> log <sub>10</sub> CFU/cm <sup>2</sup> at various exposure time (sec) to RW <sup>b</sup>					
Treatments <sup>c</sup>	0.	3		5		
RW/S/0	3.80	3.14	2.92	2.54	1:53	
	± 0.19	± 0.12	± 0.43	± 0.41	± 0:26	
RW/A/0	3.80 ± 0.16	2.91 ± 0.14	ľ	2.51 ± 0.31		
RW/S/BSC	3.28	2.87	2.53	2.11	1.38	
	± 0.16	± 0.20	± 0.09	± 0.43	± 0.23	
RWIAIBSC	3.28	2.76	2.47	2.05	1.42	
	± 0.23	± 0.18	± 0.11	± 0.13	± 0.18	
RW/S/CA	3.51	3.16	3.04	2.28	1.39	
	± 0.07	± 0.37	± 0.24	± 0. <b>21</b>	± 0.11	
RW/A/CA	3.51	3.12	3.03	2.23	1.34	
	± 0.13	± 0.22	± 0.09	± 0.23	± 0.25	
RW/A/LS	3.50	3.05	2.67	2.26	1.38	
	± 0.22	± 0.15	± 0.17	± 0.13	± 0.23	
RW/S/LS	3.50	3.04	2.60	2.24	1.33	
	± 0.13	± 0.12	± 0.14	± 0.15	± 0.12	

<sup>&</sup>lt;sup>a</sup> Data represent the average of three broiler carcasses (n = 3) and standard error ranged from  $\pm 0.07$  for low and  $\pm 0.43$  for high

#### <sup>c</sup>Treatments were

RW/S/0 : No dip, steam RW atmosphere RW/A/0 : No dip, air RW atmosphere

RW/S/BSC: 1% Buffered Sodium Citrate dip, steam RW atmosphere RW/A/BSC: 1 / Buffered Sodium Citrate dip, air RW atmosphere

RW/S/CA : 0.5% Citric acid dip, steam RW atmosphere : 0.5% Citric acid dip, air RW atmosphere RW/S/LS : 2 % Liquid smoke dip, steam RW atmosphere

RWIA/LS : 29 Liquid smoke dip, air RW atmospher

<sup>&</sup>lt;sup>b</sup>All radiant heat treatments were at 649 °C

TABLE 2: Effect of positional orientation of chicken carcass on the surface microbial reduction when treated in a Radiant wall oven at 649 °C for 5 sec in a steam atmosphere

	TPC (Log			
Treatment	Before treatment	After treatment	Log reduction	
Breast forward	3.78 ± 0.14	2.05 ± 0.11	1.73 ± 0.03°	
Back forward	3.81 ± 0.09	2.10 ± 0.17	1.71 ± 0.08ª	

<sup>&</sup>lt;sup>a</sup> Data represent average of three broiler carcasses (n=3). Means within columns with common following letter are insignificant ( P< 0.05 ).

CHANGE COMMENCE OF THE PROPERTY OF THE PROPERT

to the desired of the designation of the content of

TABLE 3: Effect of radiant heat on the microorganisms inside the body cavity of broiler carcasses when exposed to a radiant wall at 649 °C for 5 sec in a steam atmosphere with or without buffered citric acid (BSC)

a principal de la compresencia de la compresión de la compresión de la compresión de la compresión de la compre

n in in in in the production of the second of the production of the contract of the

But the way has been been been a single or the second of t

kayan kanakaya da ing kangaran malan ing kanagaran da ing ka

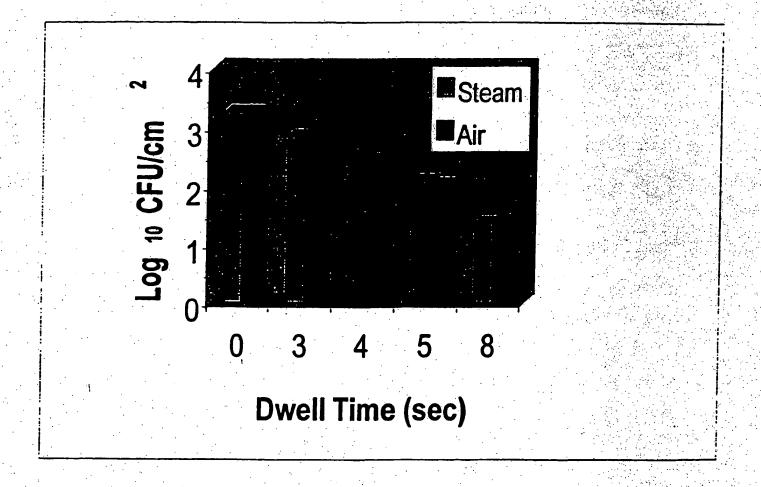
Roman British Color Carlotte Color Color

, 7. ·

	TPC(Log <sub>10</sub> (			
Treatments	Before treatment	After treatment	Log reduction	
RW	4.13 ± 0.21	4.07 ± 0.22	0.06 ± 0.01ª	
BSC/RW	3.53 ± 0.18	3.49 ± 0.16	0.04 ± 0.02°	

<sup>&</sup>lt;sup>a</sup> Data represent average of three broiler carcasses (n=3). Means within columns with common following letter are insignificant ( P< 0.05 ).

FIGURE.1. Effect of radiant heat environment on the destruction of surface microorganism on chicken surface exposed for various periods of time to a radiant wall at 649 °C for 5 sec in a steam atmosphere



#### **CHAPTER 4**

I would be a second of the language with a second

爱起的变形,还是我就不过一种好了的好点,看到这些好的,你也没一定睡觉的好好,我会不知识的不

gradien in der Heigen Meineren wirden in der delten die der der bestellt der Anders der der der der Steiler in

的表现的 1966年 1966年 1966年 1966年 1966年 1967年 1967年 1968年 196

rante de la marca de la compara de la comparte de la compara de la compara de la compara de la comparte de la

Carrier and the company of the control of the contr

## EFFECT OF RAPID SURFACE HEATING OF BROILER PARTS BY RADIANT ENERGY ON MICROBIAL QUALITY AND SHELF LIFE

PRINCE OF THE POST CONTRACTOR OF THE PROPERTY OF

<sup>&</sup>lt;sup>1</sup>Islam, M. M., Toledo R. T., and Fletcher, D. L. To be submitted to the Journal of Food Science.

### ABSTRACT

Radiant energy and buffered (pH 5.8) sodium citrate (BSC) were used to inactivate surface microorganisms on raw chicken drumsticks. Total plate counts were evaluated during storage at 0°C and 4°C. Drumsticks were dipped in BSC (0 to 10%) and exposed 3 s to a radiant wall (RW) at 788°C. Optimum BSC dip was 6%; lower levels induced less microbial reduction and higher levels gave poor product flavor. Maximum log<sub>10</sub> reduction in total surface microflora was 2 to 3, providing a shelf life to 27 d at 0°C vs. 13 d for controls or 18 d for RW treatment only. At 4°C, shelf life of BSC/RW treated drumsticks was 21 d vs. 10 d for control and 13 d for RW only treatment. Immediate chilling after RW treatment with dry ice snow prior to packaging and storage had no effect on shelf life. Skin modification by different scald procedures affected shelf life; semi-scald (52°C) shelf life at 0°C was 29 d vs. 23 d for sub-scald (60°C).

KEY WORDS: Chicken drumsticks, shelf life, radiant wall, buffered sodium citrate, scalding, microbial quality

Andrew Carlotte Colors Applied Same of the Colors of the Applied

#### INTRODUCTION

Thirty six billion pounds of broiler chicken meat were processed in the United States in 1996 (USDA, 1998). Approximately 80% of this meat was sold fresh (unfrozen). Extension of shelf life is a primary concern of the industry. Fresh poultry shelf life depends on the number of spoilage bacteria on the product immediately after processing and post processing hold temperature. Spoilage is manifested by high levels of psychrotrophic bacteria (Russell, 1997). Normal healthy broilers carry extensive microbial contamination on their feathers, skin and intestinal tract (ICMSF, 1980; Cunnigham, 1982; Cunningham and Cox. 1987). During hanging and bleeding operations, wing flapping generates aerosols which may distribute contamination to the defeathered carcasses (Sofos, 1994). In addition, the moist and warm equipment in the processing line spreads contamination among carcasses (Grau, 1986). In ageneral, contamination occurs during all processing steps including stunning, bleeding, scalding, defeathering, washing, evisceration, and washing and chilling in ice water or in cold air (Mead, 1982). Due to the rapid rate of processing, which reaches more than 6000 birds/h on some lines, contact with processing equipment favor the spread of microorganisms. Certain processing practices make control of microbial contamination more difficult with poultive (Mead. 1989). It is traditional for the carcass to remain whole throughout the process, thus making it difficult to remove the intestines without breakage through a relatively small opening in the abdomen. The need to retain the skin provides a complex surface, which is especially conducive to the entrapment of bacteria because of the numerous pores present following feather removal (Thomas and McMeekin, 1980). After evisceration and final wash, carcasses are immersion

chilled in a communal ice bath. Although rapid chilling reduces bacterial growth the process also results in cross contamination of carcasses (Lillard, 1982). The most common spoilage bacteria of refrigerated poultry are Pseudomonas. Acinetobacter, and Lactobacillus (Elliott et al., 1995). Pseudomonas spp. becomes the predominant organisms on the surface of spoiled poultry. Populations of bacteria on surfaces of raw poultry carcasses at the end of processing vary, but typically the range is from 103 to 105 aerobic mesophilic organisms per cm2 (ICMSF, 1980). Since bulk chicken drumsticks must be obtained from several birds and are subjected to considerably more handling than are intact poultry carcasses, they may contain greater indigenous micro flora than other higher value parts of the chicken. Many bacteria adhere firmly to poultry carcasses during processing (McMeekin and Thomas, 1978). Several approaches have been suggested to reduce the level of microbial contamination on poultry during processing and storage. The application of chlorine (Villareal et al., 1990), organic acid (Lillard et al., 1987) or sorbate (Robach, 1979) dips has been used to sanitize meat and poultry carcasses. This approach requires relatively long treatment times (2-120 min) and typically only small reductions (≤ 1 log cycles) in bacterial count have been achieved. Also, these dips had a serious detriment on the appearance and sensory quality of the products. Ultrasonic energy (Sams and Feria, 1991) and ultraviolet radiation (Stermer et al., 1987) treatments have also been considered, but were ineffective for products with irregularly shaped surfaces. Ionizing radiation is effective in decontaminating poultry carcasses (Mulder et al., 1977) but its application may be hindered by cost and current consumer resistance. Modified atmosphere packaging to extend shelf life of fresh poultry has proven to have some merit, (Finne, 1982) however, there is

a big risk of growth of any facultatively anaerobic or anaerobic psychrotrophic pathogens. Other potential non-thermal methods to extend shelf-life such as Pulsed Electric Fields (PEF) and Pulsed High-intensity Light (PHIL) technology (Yousef, 1996), High Hydrostatic Pressure (HHP) Raffalli et al., 1994), Bacteriocins (Shefet et al., 1995; Crosby, 1998) etc. have been tried with limited success. Flash steam heating followed by evaporative cooling (Morgan, et al., 1996, Cygnarowicz-Provost, 1994) was reported to be effective in some cases. But, this method is not yet fully developed nor commercially applied. As no other method of food preservation to replace heat has yet been developed, we investigated a new approach of applying heat to the product. We hypothesize that radiant energy of adequate intensity will rapidly heat a surface to kill microorganisms while rapid dissipation of this heat will prevent development of a cooked appearance. In addition, rapid surface heating also evaporates moisture from the surface concentrating any applied antimicrobial agent on that surface prior to the radiant heat exposure. In a previous work (Islam and Toledo, 1989) we demonstrated the effectiveness of radiant energy as an antimicrobial treatment for exposed surfaces of raw poultry. Since the interior cavity of whole dressed broilers could not receive the radiant energy, it was concluded that the treatment would be more effective for cut-up parts since all surfaces can be exposed to the radiant energy. objectives of this study were: to investigate microbicidal effects of surface application of buffered sodium citrate, pH 5.8, and radiant energy from a high temperature radiant wall on microorganisms on broiler parts; and to determine if the type of skin surface resulting from different scalding treatments has an influence on the microbicidal effects of the treatment.

and the second of the control of the second of the second

### **MATERIALS AND METHODS**

### Radiant energy source

Radiant energy was obtained from a RW oven (Model 12-36, Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA). The oven was previously described by Islam and Toledo (1998). The manufacturer improved the unit used in the present work to provide a higher burner capacity thus allowing the RW temperature to be maintained at 788°C.

公孙 网络人名英格兰格 网络人名

### Antimicrobial agent

Based on previous studies by Islam and Toledo (1998), buffered sodium citrate (BSC), pH 5.8 was used. BSC was obtained from WTI Inc., Highland, NY).

Various concentrations of this solution (w/v) were prepared by mixing appropriate quantities of powdered BCS to corresponding appropriate quantities of deionized water.

# About Broiler parts were a first of the company of the best place of the company of the company

For our first experiment, broiler drumsticks were obtained from a local processing plant. The drumsticks were mechanically severed from carcasses within 1 h of exit from the chiller. The drumsticks were then, packed in ice, and transferred to the laboratory and treated within 1 h

For our second experiment, drumsticks were also obtained from broilers processed in the pilot processing facility of the Department of Poultry Science, University of Georgia, Athens, to evaluate the effects of scald treatments on inactivation of surface microorganisms by radiant energy. Forty live chickens (6 to 7 weeks old) were divided into two groups of 20 birds each. Each group of birds was hand slaughtered and scalded either at 52°C (semi-scald, 125°F) to leave the epidermis intact or 60°C (sub-scald, 140°F) to remove the epidermis. The scalding

time was 90 s and picking time was 45 s in a rotary batch picker. Each group of the chicken carcasses was chilled in a static ice and water slush separately for 30 min. After draining for 30 s drumsticks from each carcass were removed by hand and brought to the Food Processing Laboratory in ice chest. Samples were treated within 2 h.

### **Treatments**

Effect of BSC concentration in 1-min dip: In this first part of the first experiment, 11 concentrations of BSC, and 3 s of exposure to the RW at 788°C were used. Microbicidal effects were evaluated as log reduction of the natural micro flora and changes in CFU during storage at 0 and 4°C. The experimental design was 11 x 2 x 2 (BSC concentration in dip x storage temperature x 2 replicates) for a total of 44 data sets. Ten drumsticks were used per data set (440 total drumsticks from the commercial plant) and 10 untreated drumsticks were saved as control per replicate and storage at each of the two storage temperatures (40 controls). For each replicate of a dip treatment, 20 drumsticks were dipped 1 min in BSC solutions (0 to 10% in 1% increments) then placed on a wire mesh screen to drain for 30 s. Drumsticks were then individually exposed to radiant heat. The treated drumsticks were caught from the conveyor as they emerged from the RW oven directly into sterile Stomacher pouches (Seward Medical, London). Equal numbers (10 each) of these individually bagged drumsticks were stored at 0°C and 4°C

Verification of optimum dip and RW exposure and effect of rapid chilling after RW exposure. In the second part of the first experiment, 100 drumsticks from the commercial plant (10 per treatment) were treated as follows:

Description	Designation Designation
6% BSC dip, RW exposed, no post chill	RW/BSC
6% BSC dip, RW exposed, post chilled	RW/BSC/PC
no dip, RW exposed, no post chill	RW
no dip, RW exposed, post chilled	RW/PC
no dip, no RW, no post chill	CONTROL

Treated samples were stored at 0 and 4°C. All RW exposure was at 788°C for 3 sec. When a dip was used, all 10 drumsticks per treatment were immersed in the 6% BSC solution and drained before RW exposure as described above. Post-chill was conducted to remove residual heat from the RW exposed drumsticks prior to storage. This was achieved by applying dry ice snow on the drumsticks before sealing the stomacher bags in which they were stored.

radiant energy: Chicken drumsticks used for the second experiment were processed in the pilot processing plant as described earlier. Twelve drumsticks were used per treatment. After treatment, each drumstick was individually bagged as previously described and stored at 0°C. The following treatments were performed:

	esignation
Semi-scald, no dip, no RW exposure	Α
Semi-scald, no dip, RW exposed	A1
Semi-scald, 6% BSC dip, RW exposed	A2
Sub-scald, no dip, no RW exposure	<b>B</b> ,
Sub-scald, no dip, RW exposed	B1
Sub-scald, 6 % BSC dip, RW exposed	B2

tegak kapatentag tilagapan sa kinistit talah dapat besa selagai tengan besa sa sebesa sebesa setian sebiat seb

# Sampling and enumeration:

Drumsticks from the commercial plant. Immediately following treatment and after 2, 5, 10, 13, 18, 21, 23, 25, and 27 d of storage at 0°C and 4°C, one drumstick from each treatment was removed for evaluation and TPC enumeration. All samples were evaluated subjectively by at least two laboratory workers for odor and appearance upon opening of the bag in which they were stored. Each sample in a sterile Stomacher bag was weighed. Approximate amounts of 0.1% sterile peptone was added to each sample to give a ratio of 1.0 ml of peptone to 1.0 cm<sup>2</sup> of sample surface area according to Goresline and Haugh (1959). The samples were prepared by shaking the bag vigorously 50 times in 1 ft arcs at approximately 3 shakes/sec. Total plate counts (TPC) were made on the appropriate decimal dilution of the samples in sterile 0.1% peptone by standard pour plate method using plate count agar (Difco, Detroit, MI). Duplicate plates were made on all samples and incubated for 24 h at 32°C. This time and temperature of incubation were found to allow rapid growth of the bacterial colonies without causing the colonies to touch, leading to erroneous results in counting (Elliot, et al., 1995). Both plates at a dilution giving 30 to 300 CFU/plate following incubation were counted using a Quebec dark field colony counter Model 3330 (American Optical Company, Buffalo, NY) and average of the two plates were reported.

Drumsticks from the pilot plant. In the second experiment, the samples from the controlled scalding processes were analyzed by the skin excision and maceration technique. Immediately following treatment (day 0) and after 2, 5, 10, 13, 18, 21, 23, 25, 27 and 29 d of 0°C storage, one drumstick from each treatment was sampled for microbial enumeration. The two samples (a 1 sq. inch skin samples aseptically removed from the middle area of a drumstick and the whole drumstick)

were then analyzed separately by the two following methods: skin maceration and the whole drumstick rinse. In the skin maceration techniqu, each skin piece was homogenized with 100 ml of sterilized 0.1% peptone water in a Stomacher 400 lab blender (Seward Medical, London) for 60 sec. Dilutions of the homogenate were made with sterilized peptone water (0.1%). Total plate counts (cfu/ml of rinse water) were made in duplicate pour plates using plate count agar (Difco, Detroit, Ml) with plate incubation at 32°C for 24 hours. The surface area of each drumstick was calculated from its weight using the formula: Surface Area (cm²) = 85.6 +[1.41 x wt. (g).] (Goresline and Haugh 1959). Results were recorded as CFU/cm² of skin surface.

For the whole drumstick rinse method, same procedure for microbial enumeration was followed as described in the first experiment.

# RESULTS AND DISCUSSION

事。"在是你们的"你们"——"你们",这个一样,一个一样,"你可能说,我没有做什么没想到你就没

Effect of BSC concentration in the pre-dip

3-1

Increasing concentrations of BSC in the dip resulted in lower viable organisms in the treated samples immediately after treatment (Table 1). Untreated controls showed log (CFU)/ml of rinse of 4 which compares with data from Islam and Toledo (1998) of log (CFU)/cm² of 3.3 to 3.8 in whole broiler carcasses. Log reduction with 1% BSC dip and 3 s exposure to RW at 788°C (Table 1) was 1.9 compared to 1.2 previously reported by Toledo and Islam (1988) with 1% BSC dip and 5 s exposure to RW at 648°C. The higher RW temperature induced more inactivation with the same dip and exposure tim. Increasing dip concentration increased the log reduction to a full 4 log cycle reduction with a BSC dip concentration of 8% or higher. As expected, higher

initial counts before storage resulted in faster increase of TPC and for the same treatment, a higher storage temperature resulted in higher growth rate of spoilage organisms (Table 2).

The effectiveness of the combinations of BSC dip and RW exposure on storage life of the drumsticks is shown in Figs.1 (A and B) for storage at 0 and 4 °C, respectively. The useful shelf life is defied as the time at which the total bacteria count reached 107/ml. This limiting TPC is used since it generally correlates with the onset of detectable off-odor of spoilage. This was observed in the odor of samples evaluated before microbial evaluation in the present study. Other studies (Robach, 1979) also used this microbiological criteria for spoilage of poultry. There was a 5-day difference in reaching 107/ml between 0% BSC dip and RW exposed samples compared to control samples at both 0°C and 4°C storage. BSC dip up to 3% with RW exposure did not improve shelf life over controls at 4°C, while dip of 4% and 5% BSC extended the shelf life 10 days above those of controls. Dipping in BSC without RW exposure did not significantly increase the shelf life compared to control samples. A dip in 6% BSC added 11 days to the shelf life of poultry over control samples even at 4°C storage. The shelf life was double that of control samples. Similar results are shown for storage at 0°C. Controls spoiled at 12 d at 0°C compared to 10 d at 4°C. However, the difference in shelf-life between controls and treated samples at both storage temperatures were similar. Slime and putrid off-odors were noticed on control drums as early as 10 days at 4°C and the average counts had risen above 107 per ml and spoilage was clearly evident in the smell of all control drumsticks at this point in storage. In contrast, RW treated chicken drumsticks had average counts below 107 until 18 d storage at 4°C while those

treated with RW and 6% BSC had shelf life up to 21 d. Similarly, signs of spoilage did not appear until 21 d in RW treated samples stored at 0°C while the control spoiled in 13 d. RW treated drumsticks predipped in 6 % BSC had shelf life of 27 d at 0°C. Although dipping in BSC concentrations greater than 6% showed higher log reduction just after RW treatment, there appears to be no difference in the shelf life compared to those dipped in 6% (Figs. 1 A and B). Thus, the optimum BSC concentration for the dip appears to be 6%.

Verification of optimum dip and effects of rapid chilling following RW exposure:

Figs. 2(A and B), shows results of 6% BSC pre-dip, RW exposure and rapid chilling post RW exposure on log reduction and microbial proliferation during storage. As expected, the highest shelf life of 27 d (Fig. 2A) for the RW/BSC and RW/BSC/PC treated drumsticks stored at 0°C. This verifies previous results for the same treatments (Fig. 1A). The influence of quick chilling by dry ice post-RW treatment was not evident. The curves for the microbial population with storag time were very similar with or without post-chill. Results for the 4°C stored samples of the same treatments (Fig. 2B) follow the same trend as for those at 0°C. Whill the control sample at 4°C had spoiled by 10 days, the RW/PC samples spoiled at 13 d and RW/BSC/PC samples were spoiled in 21 days. Post chilling did not enhance the shelf life. (Table 3).

Effect of skin condition as influenced by scald temperature: Prior to scalding and mechanical defeathering, the skin surface is rough and folded, with thin cornified cells in various stages of exfoliation (Connor, et al, 1987). The stratum corneum and stratum germinativum which constitute the epidermis are separated from underlying dermal tissue by a basal lamina (Matoltsy, 1969). After a sub-scald process (60°C), the entire epidermis is removed during defeathering and the

exposed dermal tissue provides a new surface for colonization by microorganisms (Thomas and McMeekin, 1980). Semi-scald (52°C), by comparison, do not facilitate removal of the epidermis. After scald/defeatheirng treatments, the skin surface retains a film of processing water, which invariably contains insoluble and soluble organic matter plus large numbers of bacteria (Thomas and McMeekin, 1980). This film of water, which appears to play a central role in contamination, is initially derived from the scald tank and water applied during defeathering which usually is water reused from processes downstream such as chiller water overflow. Obviously, the lethal effect of water held at 60°C (sub-scald) would be considerably greater than that at 52°C (semi-scald). We observed 0.6 log less microorganisms on sub-scalded compared to semi-scalded drumsticks enumerated by the rinse method (Table 4). However, the difference was not observed in skin maceration method. The difference is due to the recovery method for surface microorganisms, since there would be no expected difference in actual numbers. The film of water that contains most of the organisms on the surface originates from the water used to chill the carcass. The small difference in TPC between the sub- and semi-scalded drumstick would have no effect on the shelf life in subsequent storage if no further treatments were applied. However, with BSC dip followed by RW treatments, there was a significant difference on the microbiological load of the sub-scalded and semi-scalded drumsticks and the changes in numbers during storage. Figs. 3(A and B) show the TPC of semiscalded as well as sub-scalded chicken drumsticks enumerated by rinse and skin maceration methods respectively. Interestingly, BSC dipped and RW treated drumsticks that were sub-scalded had a shelf life of only 23 d compared to 29 d for semi-scalded drumsticks. Similarly, only RW treated sub-scalded drumsticks had a

shelf life of 21 d compared to 25 d for semi-scalded drumsticks. But when we compare the control samples, sub-scalded drumsticks had a shelf-life of 18 d vs. 13 d for semi-scalded drumsticks. Radiant heat appears to be less destructive to microorganisms on the sub-scalded skin surface. It could be due to the fact that during scalding removal or damage of the epidermal layer exposes a new surface for contamination, which is smoother and less hydrophobic, but is deeply channeled. Microorganisms firmly attached to these channels are less likely to be affected by the radiant heat. This is further confirmed by the fact that consistently higher TPC were obtained by the skin maceration method compared to rins method for similarly treated sub-scalded drumsticks. A number of studies, including that of Avens and Miller (1970) and Lillard (1983) showed that skin excision plus blending resulted in higher bacterial recovery than those obtained by the rinse method. Bacteria, which can not be rinsed off, have been considered firmly attached to meat or skin surfaces. It has been assumed that blending and stomaching results in as complete a recovery of attached bacteria as possible, whereas the rinse or swab method does not necessarily recover all bacteria on poultry tissue (Notermans and Kampelmacher, 1975).

# Figure 80 central particular in the particular Conceusion | 12 central particular in the conceusion | 12 central p

Assuming proper refrigeration is maintained during distribution and retail, RW treatment results in improved microbiological quality and potentially greater shelf life and safety for raw poultry parts. Adding a 6% BSC solution dip before RW exposure greatly increased the shelf life. Rapid chilling of RW treated chicken drumsticks was ineffective on microbial quality. The epidermis on the chicken skin plays a vital role on the keeping quality. In general, when

Barrio (Moral Maria Caraller Caraller Caraller of Caraller Caralle

epidermis is left on the skin, the shelf life of RW treated drumsticks was increased due to better exposure of microorganisms to radiant heat facilitating their destruction.

# REFERENCES REFERENCES

Avens, J.S. and Miller, B.F. 1970. Optimum skin blending method for quantifying poultry carcass bacteria. Appl. Microbiol. 20:129

Control of the Contro

- Connor, J.T., McMeekin, T.A., and Patterson, J.T. 1987. Prevention of microbial contamination in the poultry processing plant. In "Elimination of Pathogenic Organisms from Meat and Poultry," (Ed.) F.J.M. Smulders, p. 163. Elsevier Science Publishers B.V., New York, NY.
- Cunningham, F.E. 1982. Microbiological aspects of poultry and poultry products— An update. J. Food Protect. 45:1149
- Cunningham, F.E., and Cox, N.A. 1987. "The Microbiology of Poultry Meat Products." Academic Press, New York, NY.
- Crosby, D.E., Harrison, M.A., Toledo, R.T., and S.E. Craven. 1998. Use of modified atmosphere packaging and a nisin-EDTA treatment to increase shelf life of poultry products. (In press)
- Cygnarowicz-Provost, M, Whiting, R.C., and Craig, J.C. Jr. 1994. Steam surface pasteurization of beef frankfurters. J. Food Sci. 59:1
- Elliott, P.H., Tomlins, R.I. and Gray, R.J.H. 1995. Control of microbial spoilage on fresh poultry using a combination potassium sorbate / carbon dioxide packaging system. J. Food Sci. 50:1360.
- Finne, G. 1982. Modified and controlled atmosphere storage of muscle foods. Food Technol. 36:128.
  - Gill, C.O. and Penney, N. 1977. Penetration of bacteria into meat. Appl. Environ. Microbiol. 33:1284.
  - Goresline, H. E. and Haugh, R. R. 1959. Approximation of surface areas of cutup chicken and use in microbiological analysis. Food Technol. 13:24.

en en en en 18 antale en 18 antale en 18 antale en Esperifica en 20 antalegan a \$ En 18 antale en 18

- Grau, F.H. 1986. Microbial ecology of meat and poultry. In "Advances in Meat Research, vol.2, Meat and Poultry Microbiology," (Eds.) A.M.Pearson and T.R. Dutson, p. 1. AVI, Westport, Connecticut.
- Harper, J.C. 1976. Chap.12, In "Elements of Food Engineering," AVI Press, Westport, Connecticut.
- International Commission on Microbiological Specifications for Foods (ICMSF). 1980. "Microbial Ecology of Foods. Vol.2. Food Commodities." Academic Press, New York, NY.
- Islam, M.M. and Toledo, R.T. 1998. Inactivation of micro flora on whole broiler carcasses using radiant heat and antimicrobial additives. To be submitted to J. Food Sci.
- Lillard, H.S. 1982. Improved chilling systems for poultry. Food Technol. 36:58.
- Lillard, H.S. 1983. Comparison of sampling methods for Escherichia coli and total aerobic counts on broiler carcasses. J. Food Protect. 46:781.
- Lillard, H.S. 1990. Impact of commercial processing procedures on bacterial contamination of broiler carcasses. J. Food Protect. 53:202.
- Lillard, H.S. 1994. Effect of TSP on Salmonella attached to chicken skin. J. Food Protect. 57:465.
- Lillard, H.S., Blankenship, L.C., Dickens, J.A., Craven, S.E., and Shackelford, A.D. 1987. Effect of acetic acid on the microbiological quality of scalded picked and unpicked broiler carcasses. J. Food Protect. 50:112.
- Matolsky, A.G. 1969. Keratinization of the avian epidermis: an ultrastructural study of the newborn chick skin. J. Ultrastruct. Res., 29:438.
- McMeekin, T.A. and Thomas, C.J. 1978. Retention of bacteria on chicken skin after immersion in bacterial suspensions. J. Appl. Bacteriol. 45: 383.
- Mead, G.C. 1982. Microbiology of poultry and game birds. In "Meat Microbiology," (Ed.) M.H. Brown, p. 67. Applied Science Publishers, London.

KIND OF THE PARTY AND A STATE OF THE SEAL OF THE SEAL

- Mead, G.C. 1989. Hygiene problems and control process contamination. In "Processing of Poultry," (Ed.) G. C. Mead, p. 183. Elsevier Applied Science, London.
- Morgan, A.I., Radewonuk, E.R., and Scullen, O.J. 1996. Ultra high temperature short time surface pasteurization of meat. J. Food Sci. 61:1216.

Mulder, R.W., Notermans, S and Kampelmacher, E.H. 1977. Inactivation of Salmonella on chilled and deep-frozen broiler carcasses by irradiation. J. Appl. Bacteriol. 42:179.

Same of the State of the State of the

- Notermans, S., and Kampelmacher, E. H. 1975. Studies of different sampling methods for the determination of bacterial counts from frozen broilers. J. Appl. Bacteriol. 39:125.
  - Olson, J.C., Jr. and Nottingham, P.M. 1980. In "Microbial Ecology of Foods, vol.1, Factors affecting life and death of microorganisms," (Ed.) International Commission on Microbiological Specifications of Foods, p.1. Academic Press, Inc., New York, NY.
  - Raffalli, J., Rosec, J.P., Carlez, A., Dumay, E., Richard, N., and Cheftel, J.C. 1994. High pressure stress and inactivation of *Listeria innocua* in inoculated dairy cream. Sci. Alim. 14:349
  - Robach, M.C. 1979. Extension shelf life of fresh, whole broilers using a potassium sorbate dip. J. Food Protect. 42:855.
  - Russell, S.M. 1997. A rapid method for predicting the potential shelf life of fresh broiler chicken carcasses. J. Food Protect. 60:148.
  - Sams, A.R. and R. Feria. 1991. Microbial effects of ultrasonication of broiler drumsticks skin. J. Food Sci. 56:247.
  - Shefet, S.M., Sheldon, B.W., and Klaenhammer, T.R. 1995. Efficacy of optimized nisin-based treatments to inhibit *Salmonella typhimunium* and extend shelf life of broiler carcasses. J. Food Protect. 58:1077.
  - Sofos, J.N. 1994. Microbial growth and its control in meat, poultry and fish. In "Quality attributes and their measurements in meat, poultry, and fish products," (Ed.) A.M. Pearson and T.R. Dutson, p. 359. Chapman & Hall, London.
  - Stermer, R.A., Lasater-Smith, M., and Brasington, C.F. 1987. Ultraviolet radiation An effective bactericide for fresh meat. J. Food Protect. 50:108.
  - Thomas, C.J. and McMeekin, T.A. 1980. Contamination of broiler carcass skin during commercial processing procedures: an electron microscopic study. Appl. Environ. Microbiol. 40:133.
  - USDA (United States Department of Agriculture). 1998. Agricultural Statistics, 1998. United States Government Printing Office, Washington, DC.

Villareal, M.E., Baker, R.C., and Regenstein, J.M. 1990. The incidences of Salmonella on poultry carcasses following the use of slow release chlorine dioxide (Alcide). J. Food Protect. 53: 465.

Was Son John School & House

AND THE PROPERTY OF THE PARTY OF

· 医含化剂 经基础 医皮肤 医皮肤

Yousef, A.E. 1996. Pulsed light and pulsed electric fields for cold-pasteurization of foods. Presented at the Annual Meeting of the Food Research Institute. University of Wisconsin, Madison, May 30.

The All Marin Court of the Property of the Court of the Section of the Court of the

to be the same to the first of the property of the property of the same

TOP TO STATE OF THE STATE OF TH

The second s

Some plant waster was S. Asiaki.

en de tradições de la especia de la compania de la especia de la especia de la especia de la especia de la esp La especia de la especia d

以及 (對) 的 "我们是一种" "不知"的"说话" "我们,我们是我们的我们确定的是我们就解决。

A CANAGA CAMBANA CAN MARAKATAN Marakatan

and the property of the control of t

THE PARTY OF THE STATE OF THE PARTY OF THE P

The province of the configuration of the configuration of the province of the configuration o

不足,这是是是我们,我还是你只好的我,不是,我们就把一个我们就把什么多数,这一个我们就**会找了这个人的**孩子。**我**说了,这**是**我也

the entry of the financial of the boundary of the entry of the entry of the control of the contr the Control of the Co

and the second of the state of the second party of the second of the second of the second of the second of the LANGE OF THE CONTROL OF THE PROPERTY OF THE PR

and the second and the control of the second of the control of the second second control of the control of the second of the sec The American Committee of the Committee

The desirance for the later where the later of the confidence of the confidence of the confidence of

The state of the second of the radio altimata digentito in tripe in properti della Potto della consequia in casa di collectioni della di della

TABLE 1 :Total bacterial populations (log10 CFU/ml) recovered from chicken drumsticks dipped in various buffered sodium citrate solutions for 1 min, exposed to a radiant wall at 788°C for 3 s and held for 0, 3, 5, 10, 13, 18, 21, 23, 25, or 27 d at 0°C.

	<del></del>		· · · · · · · · · · · · · · · · · · ·		<del></del>		<del> </del>	·	<del></del>	
			<b>№</b>	lean <sup>A</sup> k	og <sub>10</sub> CF	Us per	ml of s	urface	rinse	
Treatment	<u> </u>	<u> </u>		· /	<u> </u>	1	· .	1.7 y 3.	<u> </u>	·
BSC/RW	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day
	0	3	5	10	13	18	21	23	25	27
0 %	2.5	2.7	3.4	4.5	5. <b>5</b>	7.0 <sup>B</sup>	NT	NT	NT	NT
1 %	2.1	2.5	3.3	4.3	5.3	7.3 <sup>B</sup>	NT	NT	NT	NT
2 %	2.0	2.4	3.1	4.1	5.0	6.1	7.3 <sup>B</sup>	NT	NT	NT
3 %	2.1	2.3	3.0	3.9	4.5	4.9	7.0 <sup>B</sup>	NT	NT	NT
4 %	2.0	2.1	2.9	3.6	4.0	4.3	6.1	7.1 <sup>B</sup>	NT	NT
5 %	1.4	1.9	2.5	3.1	3.9	4.2	5.5	6.7	7.0 <sup>B</sup>	NT
6 %	1.2	1.5	2.1	2.9	3.2	3.9	4.6	5.8	6.5	7.1 <sup>B</sup>
7 %	1.0	1.3	2.0	2.8	3.3	4.0	4.6	5.6	6.3	7.0 <sup>B</sup>
8 %	ND	1.1	1.9	2.6	3.1	4.1	4.5	5.3	6.1	7.1
9 %	ND	1.0	1.7	2.7	3.1	4.0	4.5	5.2	6.0	7.1
10 %	ND	ND	1.4	2.3	2.9	3.8	4.2	5.0	5.8	7.0
Control	4.0	4.7	5.1	5.8	7.0	NT	NT	NT	NT	NT

NT- not tested

ND- not detected

A — Number of observations per mean n = 6
 B — Italicized numbers indicate that spoilage levels have been

TABLE 2 :Total bacterial populations (log<sub>10</sub> CFU/ml) recovered from chicken drumsticks dipped in various buffered sodium citrate solutions for 1 min, exposed to a radiant wall at 788°C for 3 s and held for 0, 3, 5, 10, 13, 18, 21, 23, 25, or 27 d at 4°C.

				:						
			M	lean <sup>A</sup> lo	0g <sub>10</sub> CF	Us per	ml of s	surface	rinse	
Treatment	4			Maria Sun	. 1					
BSC/RW	Day	Day	Day	Day	Day	Day	Day	Day	Day	Day
	σ	3	5	10	13	18	21	23	25	27
0 %	2.5	3.2	5.0	6.3	7.0 B	NT	NT	NT	NT	NT
1 %	2.1	3.2	4.9	6.1	7.1 <sup>B</sup>	NT	NT	NT	NT	NT
2 %	2.0	3.0	4.7	6.0	7.0 <sup>B</sup>	NT	NT	NT.	NT	NT
3 %	2.1	3.2	4.5	5.9	7.0 <sup>B</sup>	NT	NT	NT	NT	NT
4 %	2.0	3.1	4.3	5.2	6.3	7.4 <sup>B</sup>	NT	NT	ŃТ	NT
5 %	1.4	3.0	4.2	5.0	6.1	7.1 B	NT	NT	NT	NT
6%	1.2	2.5	3.7	4.6	5.1	6.3	7.0 B	NT	NT	NT
7 %	1.0	2.5	3.5	4.4	5.0	6.1	7.0 <sup>B</sup>	NT	NT	NT
8 %	ND	2.4	3.3	4.5	5.3	6.4	7.0 <sup>B</sup>	NT	NT	NT
9 %	ND	2.0	3.0	4.2	5.0	6.1	6.8	7.4 B	NT	NT
10 %	ND	2.0	2.9	4.0	4.9	5.4	6.5	6.9	7.2 <sup>8</sup>	NT
Control	4.0	5.2	6.6	7.8 B	NT	NŤ	NT	NT	NT	NT

<sup>^ -</sup> Number of observations per mean n = 6

ND- not detected

B - Italicized numbers indicate that spoilage levels have been reached

NT-not tested

TABLE 3: Effect of post-radiant heat rapid chilling on the shelf life of chicken drumsticks exposed to a radiant wall at 788°C for 3 s and stored at 0 and 4°C.

		The control of the co	Shelf life ( days )		
	Treatment	Chilling	No Chilling		
0°C					
	Control RW	NT 18	13 18		
• • • • • • • • • • • • • • • • • • • •	BSC/RW	<b>27</b>	27		
4°C	er et et Marie de gesel Marie de la companya de la La companya de la co				
	Control RW	NT 13	10 13		
	BSC/RW	21	21		

NT- not tested

RW- treated only by radiant heat

BSC/RW - dipped in 6% buffered sodium citrate for 1 min and exposed to RW

TABLE 4: Total bacterial populations (log<sub>10</sub> CFU/cm<sup>2</sup> ± SE) recovered by whole drumstick rinse method and skin maceration method from chicken drumsticks processed at two different scalding temperatures (52 and 60°C) and exposed to a radiant wall (RW) at 788°C with or without a predip in 6% buffered sodium citrate (BSC) solution.

	TPC <sup>b</sup> Rins	se Method	TPC <sup>b</sup> Maceration method		
Samples <sup>a</sup>	Log CFU/cm <sup>2</sup>	Log Reduction	Log CFU/cm <sup>2</sup>	Log reduction	
Α	4.3 ±0.1	•	3.8 ±0.1	<u>-</u>	
A1	1.6 ±0.2	2.7 ±0.3 <sup>A</sup>	1.8 ±0.1	2.0 ±0.2 <sup>B</sup>	
A2	1.4 ±0.1	2.9 ±0.2 <sup>A</sup>	1.3 ±0.2	2.5 ±0.3 <sup>c</sup>	
В	3.7 ±0.2	-	3.9 ±0.1	-	
B1	1.9 ±0.3	1.8 ±0.5 <sup>B</sup>	2.4 ±0.1	1.5 ±0.2 <sup>D</sup>	
B2	1.7 ±0.2	2.0 ±0.4 <sup>B</sup>	1.7 ±0.1	2.2 ±0.2 <sup>E</sup>	

<sup>a</sup> Samples are:

A - semi-scald (52°C), control

A1 - semi-scald, treated only by radiant heat

A2 - semi-scald, 1-min dip in BSC and then treated by radiant heat

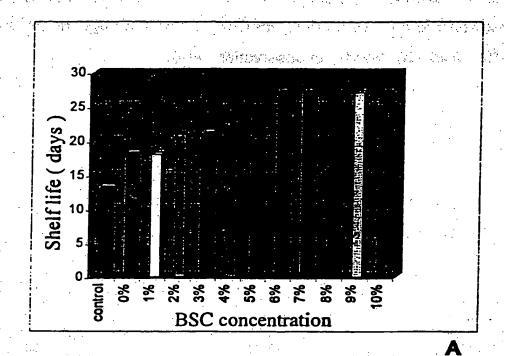
B - sub-scald (60°C), control

B1 - sub-scald, treated only by radiant heat

B2 - sub-scald, 1-min dip in BSC and then treated by radiant heat

<sup>b</sup> Mean  $\pm$  SE. Means within columns followed by the same letters are not significantly different ( P < 0.05 ). n = 6

FIGURE 1: Effect of dipping for 1 min in various concentrations of buffered sodium citrate (BSC) solution on the shelf life of chicken drumsticks prior to exposure to a radiant wall at 788°C for 3 s and storage at 0°C (Graph A) and at 4°C (Graph B). Number of observations n=6.



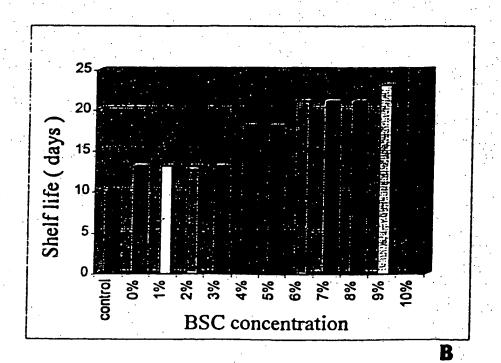
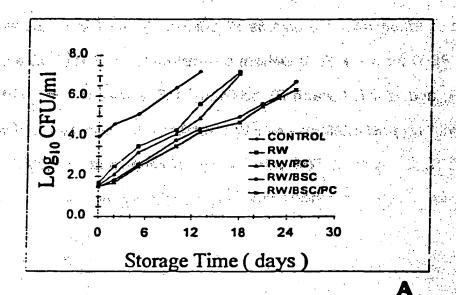


FIGURE 2: Effect of post-radiant heat rapid chilling on the growth characteristics of surface microorganisms of chicken drumsticks exposed to a radiant wall at 788°C for 3 s with or without a 1-min dip in 6 % BSC and storage at 0°C (Graph A) and at 4°C (Graph B). Various treatments are: -\*- control; --- RW treatment with no post-chilling; --- RW treatment followed by rapid post-chilling; --- dip in BSC followed by RW with no post-chilling; and -\*- dip in BSC followed by RW with rapid post-chilling. Number of observations n=6.



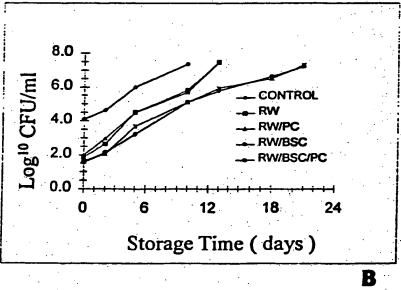
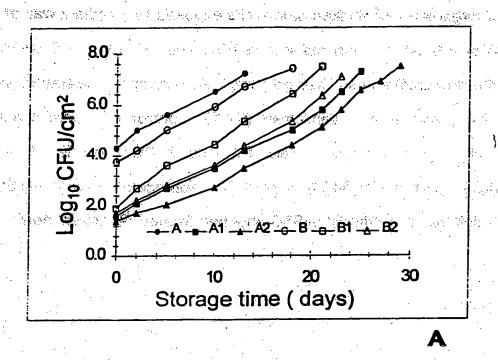
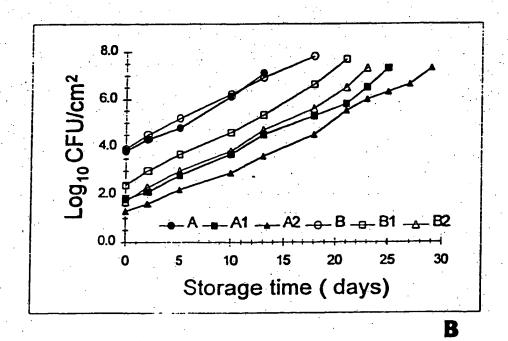


FIGURE 3: Effect scalding temperatures on the growth characteristics of surface microorganisms of chicken drumsticks exposed to a radiant wall at 788°C for 3 s with or without a 1-min dip in 6 % BSC and stored at 0°C as enumerated by whole drumsticks rinse method (Graph A) and skin maceration method (Graph B). Samples are: A - semi-scald (52°C), control; A1 - semi-scald, treated only by radiant heat; A2 - semi-scald, 1-min dip in BSC and then treated by radiant heat; B - sub-scald (60°C), control; B1 - sub-scald, treated only by radiant heat; B2 - sub-scald, 1-min dip in BSC and then treated by radiant heat;

THE STATE OF THE STATE OF





#### **CHAPTER 5**

# REDUCTION OF SALMONELLA AND CAMPYLOBACTER ON FRESH CHICKEN DRUMSTICKS BY TREATMENT IN A RADIANT WALL OVEN

The Control of the Co

BANGARAN TAKA BANGKATAN TAKA BANGTAN BANGTAN TAKABAKAN PABA

Barrier and the second of the second and the second

to the first few courses were to the course of the course of the second course of the course of the course of

THE REPORT OF THE PROPERTY OF

elas il mandali il priegi il la mesgra releva di un coli apprendenta di perendi il gibe di li li dell'apprendi

Charles that the first control of the control of th

THE TOTAL OF THE STREET STREET, AND THE STREET OF THE STREET OF THE STREET STREET, AND THE STREET OF THE STREET

The property of the second of

· 网络阿拉斯斯· 医多元,以及阿斯特尔 医多克克斯氏病 化二氯甲

1. 12. 全种类型 "我们会对一数"是基础的工程是Windows

<sup>&</sup>lt;sup>1</sup>Islam, M. M., and Toledo, R. T. To be submitted to the Journal of Food Science.

### **ABSTRACT**

No viable CFU of a nalidixic acid-resistant Salmonella typhimunium (S. typhimunium NAR) were recovered from chicken drumsticks inoculated with 100 CFU and exposed 3 s to a radiant wall (RW) at 788°C. There was no recovery from heat injury after 3 d of refrigerated storage at 4°C. However, viable CFU was detected when 1,000 CFU was inoculated and exposed to RW only. The 1,000 CFU inoculum showed no CFU recovery when drumsticks were dipped in a 6% solution of buffered sodium citrate, pH 5.8 (BSC) prior to RW exposure. No viable CFU of Campylobacter jejuni were detected on raw chicken drumsticks inoculated with 1,000 CFU and exposed to RW. Viable CFU was recovered from a 10,000 CFU inoculum. Challenge studies with large inoculum of each pathogen gave log reductions of 0.79, 1.73 and 2.32 for S. typhimunium on fresh chicken drumsticks treated respectively with only BSC, only RW and combined BSC/RW. Similar treatments on Campylobacter jejuni yielded 1.45, 2.41, and 3.36 log reduction respectively.

KEYWORDS: Salmonella, Campylobacter, poultry, radiant heat, buffered sodium citrate, pasteurization,

### INTRODUCTION

Increased consumption of poultry products in the USA has resulted in increases in food borne illnesses associated with poultry. Pathogenic bacteria associated with poultry include: Salmonella spp. (Bryan, 1980), Listeria monocytogenes (Brackett, 1988), Staphylococcus aureus (Bergdoll, 1989), and Campylobacter jejuni ( Stem, et al., 1985). Among these microorganisms. Salmonella spp. and Campylobacter spp. are responsible for most poultry foodtransmitted illnesses (Mulder and Bolder, 1984). Poultry associated diseases are major burdens on society causing considerable suffering and loss of productivity, and adds to the cost of food production and health care (Bryan and Doyle, 1994). Among diseases acquired by ingesting undercooked or recontaminated poultry, salmonellosis and campylobacteriosis are of primary contemporary concern in the United States. Risks of acquiring these diseases are greatly influenced by the prevalence of Salmonella spp. and C. jejuni in fowl and subsequently in poultry products. Dubert (1988) estimated that 35 % of chicken carcasses in the United States are contaminated with Salmonella, and an average of 62 % by C. jejuni (Bryan and Doyle, 1994). Proper handling and cooking can adequately eliminate most risk from these pathogens on poultry (Thayer, et al., 1992). Consumer complaints and publicity have increased the need for higher standards of bacterial quality in poultry products (Shane, 1988). Federal and State governments and poultry Industry representatives are interested in reducing numbers of pathogens on poultry to reduce risk of food borne illnesses ( Sams and Feria, 1991).

The relatively high incidence of these diseases will continue unless some means is devised and implemented that will either eliminate these bacteria from poultry or drastically reduce their contamination (Bryan & Doyle, 1994). During processing even in sanitary modern processing plants, salmonellae and campylobacters are present on poultry throughout the processing steps. Scalding, defeathering, evisceration and giblet harvesting operations are the major points of transfer of microorganisms. Many studies have shown that Salmonella spp. and Campylobacter spp. attached to poultry carcasses can survive immersion in 52 to 60 °C scald water (Kim et al., 1993; Morrison and Fleet, 1985; Slavik et al., 1994). These pathogens can subsequently spread to non-contaminated carcasses during defeathering and chilling (Clouser et al. 1995, Clouser et al. 1995b). Often, greater numbers of processed carcasses and parts become contaminated than there are infected or contaminated live animals coming to slaughter. Unless poultry is heat processed or given another treatment to kill pathogens, additional removal, prevention and control procedures are needed to reduce the risk of poultry borne disease. There is an immediate need for a cost-effective approach to reduce the prevalence of Salmonella spp. and C. jejuni on poultry. Costs for effective measures that will reduce, prevent or eliminate these pathogens should be substantially lower than the estimated costs to society due to poultry-related human diseases. Moreover, these measures can encourage more poultry products consumption by reducing the consumer's concern about the safety of poultry.

A Carrier Water State

A number of control points for salmonellae and campylobacters are available to the broiler industry during live production, including use of salmonella-free feed, bio-security, and dust and vector control ( Jones, et al., 1990). However, the ultimate control points are in the slaughtering and dressing operations, which has been the primary target in the implementation of the Hazard Analysis Critical Control Point (HACCP) program (Tompkin, 1990). Elimination of gram-negative food borne pathogens, including *Salmonella* spp. and *Campylobacter* spp. at the production level is currently not feasible. Therefore, an intervention step to substantially reduce or eliminate them during processing is desperately needed to ensure the safety of raw animal products.

With respect to techniques for the inactivation of micro organisms in foods, the most widely accepted has been thermal processing. A desired outcome of a heat treatment is elimination of pathogens with minimal damage to product quality. This is being pursued in two, often complementary, ways. Firstly by the application of high temperature-short time processing and protectively packaging the treated carcasses to prevent recontamination. Secondly, by delivering heat in new ways. Very rapid surface heating for a short time is thought to be an effective method in reducing salmonellae and campylobacters on the surface of the chicken. To achieve this we used radiant energy from a high temperature radiant wall (RW), to raise the surface temperature to levels lethal to bacteria within a very short time and combining this treatment with an antimicrobial dip. Reduction or elimination of these pathogens on poultry

carcasses before the retail product reaches the consumer should reduce the risk of food borne salmonellosis and campylobacteriosis.

The purpose of this study was to evaluate the effects of RW exposure with or without a pre-dip in buffered sodium citrate, pH 5.8, on the survival of S. typhimurium<sup>NAR</sup> and C. jejuni inoculated on the skin of chicken drumsticks.

### MATERIAL AND METHODS

### Chicken drumsticks

Tray-packed chicken drumsticks were obtained from the fresh meat display case of a local supermarket 1-2 h before the treatments. The brand name of the product was noted and subsequent purchases for later experiments were of the same brand. All tray packs of the drumsticks used were stamped with a "sell by" date which was at least 10 days later than the date of purchase. Drumsticks were used directly on removal from the tray pack. Enough drumsticks were purchased at one time to conduct 3 treatments at 5 levels of inoculation of one organism. Each treatment and inoculum level consisted of 10 drumsticks.

# adition **Treatments** , which are triving in the last required the according to a recognitivity with

Drumsticks were inoculated individually with either of two gram negative pathogenic bacteria Salmonella typhimunum or Campylobacter jejuni. Inoculum levels were 0, 10, 100, 1,000 and 10,000 cells. When an anti-microbial dip treatment was used, the drumsticks were dipped first in the solution, allowed to drain for one minute before they were inoculated. The following treatments were

used: Control; 3 s exposure to RW at 778 °C (RW); dipped in a 6% solution of buffered sodium citrate, pH 5.8 (BSC) with no subsequent treatment; and; predipped in BSC followed by RW exposure (BSC/RW).

## Test organisms

Salmonella typhimurium: A nalidixic acid-resistant strain of Salmonella typhimurium (S. typhimurium NAR) obtained from the culture collection of Dr. Mark Harrison, Food Science and Technology Department, University of Georgia, Athens, was used. This organism's resistance to 200 ppm nalidixic acid was used to verify that the recovered CFUs were from the inoculum. An 18 h actively growing culture (mid-log phase of growth) on Brain Heart Infusion (BHI) agar 化抗凝红 电流振荡器 化二氯甲烷 (Difco Laboratories, Detroit, MI) slants at 37°C was washed off the slant with sterile 0.1% peptone solution (Difco). The suspension was diluted with sterile 0.1% peptone to an optical density of 0.2 at 540 nm, (Spectronic 20, Bausch and · 100 (1) (1) (1) (1) 2000年 (1987) Lomb) to give a S. typhimunum<sup>NAR</sup> population density of approximately 10<sup>7</sup> to 10<sup>8</sup> 数数据 "这个这样,这个女子就不是一定,这是我们就不是一定的这个人 CFU/ml. Serial dilutions from this stock suspension were made to get desired TO 10.66是为据据1000年增加 医乳腺囊性坏疽 医肾髓炎 计规则进行设计设计 inoculation levels. The actual number in the inoculum was determined by pour BUT THE BUTTER OF BUTTER OF THE STATE OF THE plating in triplicate, 0.1 ml of the dilution used as a source of the inoculum on BHI plates and counting CFU after 24 h incubation at 37°C. 化基性支撑 火焰 接触 编程点证据

Campylobacter jejuni: Cultures of Campylobacter jejuni (ATCC 29428) were also obtained from Dr. Mark Harrison. Inocula were prepared as described above except that *C. jejuni* was grown in brucella broth (Difco) at 42°C under a microaerophilic atmosphere. Number of organisms in appropriate dilutions of the

inoculum was determined by optical density measurements as above, and verified by surface plating. Populations of *C. jejuni* were determined by directly plating the samples on campylobacter blood-free selective media (modified CCDA-Preston with cefoperazone and amphotericin selective supplement; Oxoid, England, CM739+SR155). The plates were incubated in an atmosphere consisting of 10% CO<sub>2</sub>, 85% N<sub>2</sub> and 5% O<sub>2</sub> for 48 h at 42°C. The appearance of colonies on the petri plates was used to verify that the CFU was *C. jejuni*. Typical colonies of this strain were gray, moist, flat, and spreading. Smears from a typical colony were examined microscopically for further confirmation.

## Inoculation and recovery

A marked area of skin 5.1 x 5.1 cm<sup>2</sup> was inoculated with the appropriately diluted inoculum by depositing a 100 µL volume with a micropipette and Companies en Colon Colon en et la territa spreading this droplet evenly over the marked area with a sterile L-shaped glass. retributed and the contraction of the contraction o rod. Following inoculation, the samples were held under a laminar-flow hood for And makangan kommolik, melakal militah melakan kenangan dalam kenangan dalam kenangan dalam kenangan dalam ken 15 minutes to allow adsorption and attachment of the test organism. The The two to a section in the property and which him as it is not the party of the first backers. drumsticks subjected to the RW and BSC/RW treatments were then immediately exposed to the RW. Surviving cells of either organism were recovered from the The factor of the frequency on the foreign property and the first first foreign and the property of skin using skin maceration procedure. In the skin maceration technique, each THE CONTRACTOR OF THE PART OF marked skin area was aseptically cut and the piece was homogenized in a sterile stomacher bag with 100 ml of sterilized 0.1% peptone water in a Stomacher 400 lab blender (Seward Medical, London) for 60 sec. Serial dilutions of the KARATA TAYAR KANDARA homogenate were made with sterile peptone water (0.1%).

Viable *S. typhimurium*<sup>NAR</sup> cells were enumerated using duplicate pour plate of Bismuth Sulfate agar (Difco Laboratories) supplemented with 200 ppm nalidixic acid (1-Ethyl-1,4-dihydro-7-methyl-4-oxo-1,8-napthyridine-3-carboxylic acid; Sigma Chemicals, St. Louis, MO). Plates were incubated at 37°C for 48 h. Typical colonies of *S. typhimurium*<sup>NAR</sup> were brown or gray with a metallic sheen. The media surrounding the colony was usually brown at first, then turned black as the incubation increased. Recovered *S. typhimurium*<sup>NAR</sup> populations were reported as log<sub>10</sub> survivors per cm<sup>2</sup>.

Viable C. jejuni cells were recovered using the same procedure of skin excision and maceration in a Stomacher, as above, except that the medium and procedure used for enumeration is as described above for this organism.

General statistics

Bacterial populations were converted to log<sub>10</sub> prior to statistical analysis.

Significant differences between treatment mean populations were determined by comparing each mean pair using the Student's t-test at P< 0.05.

# RESULTS AND DISCUSSION

海南海绵 工作 化二氯甲烷酸钾 计电路 网络人名西拉马斯特斯克斯 化水管 化物管管管管 化燃烧 机电流电影器

There has been no previous work on the combined effect of intens radiant heat and decontaminate animal carcasses (USDA, 1994). Our results demonstrated that the combined BSC/RW treatments exhibited significant synergistic interaction of these two microbiocidal treatments to amplify the extent of inactivation of inoculated pathogens.

Table 1 shows the log CFU of inoculated *S. typhimurium* and *C. jejuni* recovered from control and treated chicken drumsticks. With inocula small **r** than 100 cells, there appears to be a problem with recovering the specified inoculum from the untreated inoculated surface. For example only 66% of control samples inoculated with an estimated 10 CFU of *S. typhimurium* was positive for this organism. This may be explained by the statistical probability of obtaining exactly the number of desired organisms when sampling from a very dilute solution. For example, when we took 6 - 100 μL aliquots from a suspension supposed to contain 100 CFU/ml, the actual counts from the aliquots obtained by plating were 11, 10, and 6 and 5, 9, and 13. Actual recovery from the skin surface may not be 100% therefore introducing numerous numbers were necessary.

Also shown in Table 1 is the effect of different RWO treatments on S. typhimurium AR and C jejuni inoculated at different inoculum level. Drumsticks inoculated with either 10 or 100 CFU/drumstick exhibited no viable CFU of S. typhimurium after RW treatment. However, the same treatment on drumsticks inoculated with 1,000 CFU exhibited viable S. typhimurium. The combined BSC/RW treatment showed no recovered survivors from 1,000 CFU inoculum but there were survivors from 10,000 CFU inoculum. RW and BSC/RW treatments showed no Campylobacter jejuni survivor recovery up to 1,000 CFU inoculum but both treatments showed survivors when inoculum was 10,000 CFU. The BSC dip by itself had negligible microbiocidal effect.

Survivors recovered from an inoculum about 100 CFU of *S. typhimunium* decreased significantly as the radiant wall temperature (Table 2) for the same exposure time of 3 s. No recovered CFU of *S. typhimunium* were found on drumsticks treated at 788°C. Numbers of recovered survivors tested immediately after treatment and after 3 days 4°C were not significantly different. Gram negative bacteria possess a very thin peptidoglycan layer (Murray, et al., 1965) which may offer little protection against internal turgor pressure when the cytoplasmic membrane is weakened by high temperature (Mendonca et al., 1994). The fluidity of the cytoplasmic membrane is largely a reflection of membrane lipid composition (Beuchat, 1978). Katsui et al. (1981) suggested that the change in the fluidity of membrane lipids might be linked with heat resistance of bacteria. Bowler et al. (1973) suggested that the central cause of cellular h at injury is the disruption of the membrane lipoprotein complexes or enzymes, associated with the integrity of the cell membrane.

The combined BSC/RW treatment had an synergistic effect on salmonellae and campylobacters. Table 3 shows the effect of different treatments on these pathogens. The analysis showed a consistent statistically significant difference between the control group and the three treatment groups. Neither of the individual RW or BSC treatments achieved a high degree of pathogen reduction, but when the treatments were combined, the effects were more notable. The reductions were 2.32 log for *S. typhimurium* and 3.36 for *Campylobacter jejuni* respectively. Relating this to risk, if we assume, in the worst case, that 70% of chickens in supermarkets are contaminated with salmonellae

and their numbers on chicken drumsticks follows a Poisson distribution, then the most probable number of salmonellae per drumsticks is Ln 100 - Ln 30 = 1.204 and the probability of no Salmonella on a drumstick is p = 0.30. If decontamination treatment reduced the number of Salmonella 100 fold, the most probable number becomes 0.01204 and the probability of no Salmonella on a chicken becomes 0.988. Supposing that an average family buys one pack of chicken drumsticks a week and assuming a binomial sampling distribution with P = 0.988 for selecting a contaminant pack, we have P = 1 - (52 ! / 0 ! 52 !)0.988<sup>52</sup>] = 0.466 or nearly a 50 % chance that in 1 year of weekly purchase, at least one of the purchases will be contaminated. Furthermore, Bryan (1979) reported that the lowest dose of several species of Salmonella producing a clinical response in healthy adult; humans was 105 CFU. As our studies noted above, a RWO treatment of 788°C for 3 sec would be expected to reduce the population of S. typhimurium NAR/cm² by 2.32 logs. Thus a population of 1,000 S. typhimurium NAR/cm<sup>2</sup> would decrease to approximately less than 500 cells, well below the estimated infectious dose, and a very large amount of raw RWO treated chicken would be necessary for an infectious dose to a healthy adult. Further, it has been demonstrated that heat-injured Salmonella are much more sensitive to the effects of cooking than non heat-injured organism. We thus concluded that treating chicken drumsticks in RWO at 788°C for 3 sec should provide significant protection against the presence of these Gram negative 一种公司、其他的一个大品类公司、公司公司、公司、公司、公司、董学、公司、 pathogens.

我的感情感到我们的人,这一点,你还有情感更多的人。""这么一个我们的这是一个女人,只有什么是不是<sub>这样</sub>的

It could be argued that the presented data are valid for challenge test with the organisms and would not reliably indicate the destruction of natural contaminants of these pathogens. To investigate this possibility 10 "pairs" of refrigerated chicken drumsticks were randomly purchased at local retail outlets. One member of each pair was directly examined for its level of salmonellae. While the other member was similarly examined but after BSC/RW treatment. The results are presented in Table 4. The mean salmonella count of the 10 untreated samples was 356 cells/drumsticks with a range of 0 to 3550 cells/drumsticks. The mean count of 10 treated carcasses was 13 cells/drumsticks with a range of 0 to 97 cells/drumsticks. 8 of the untreated samples were positive for salmonella contamination whereas only 3 of the treated samples were positive. Thus it was shown that BSC/RW treatment is also effective against natural contaminants of salmonellae.

# CONCLUSION

CAMP CONTRACTOR SERVICE

i ili

A combination of radiant heat and buffered sodium citrate, pH 5.8, significantly reduced or eliminated Gram-negative pathogens on chicken skin without causing a departure of appearance from the raw product. The treatment was effective for inoculum levels up to 1,000 CFU for both S. typhimunum and C. **ู่เคมาก**เลือง การเกิดเกาะ เดือง เกาะเดือง คราม เกาะเดือง เกาะเดือง เกาะเดือง เกาะเดือง เกาะเดือง เกาะเดือง เกาะ

The second state of the second se

SHE BE THE SHE SHE SHE SHE SHE SHE SHE SHE

MEST PROPERTY OF STREET

### REFERENCES -

. . . . .

- Bergdoll, M.S. 1989. Staphylococcus aureus. pp. 463-523. In M. P. Doyle (ed.). "Foodborne Bacterial Pathogens." Marcel Dekker, Inc. New York, NY.
- Beuchat, L.R. 1978. Injury and repair of gram-negative bacteria, with special consideration of the involvement of the cytoplasmic membrane. Adv. Appl. Microbiol. 23:219
- Bowler, K., Duncan, C.J., Gladwell, R.T., and Davison, T.F. 1973. Cellular heat injury. Comp. Biochem. Physiol. 45:441
- Brackett, R.E. 1988. Presence and persistence of *Listeria monocytogenes* in food and water. Food Technol. 42:162

garan laga wasaliga di bakaran basa basa basa ba

- Bryan, F.L. 1980. Foodborne diseases in the United States associated with meat and poultry. J. Food Protect. 43:140.
- Bryan, F.L. and Doyle, M.P. 1994. Health risks and consequences of Salmonella and Campylobacter jejuni in raw poultry. J. Food Protect. 58:326.
- Clouser, C.S., Doores, S., Mast, M.G., and Knabel, S.J. 1995a. The role of defeathering in the contamination of turkey skin by Salmonella species and Listeria monocytogenes. Poultry Sci. 74:723.
  - Clouser, C.S., Knabel, S.J., Mast, M.G., and Doores, S. 1995b. Effect of type of defeathering system on *Salmonella* cross-contamination during commercial processing. Poultry Sci. 74:729.
  - Dubert, W.H. 1988. Assessment of Salmonella contamination in poultry past, present, and future. Poultry Sci. 67:944.

Jones, F.T., Axtell, F.C., Rives, D.V., Scheideler, S.E., Traver, F.R. Jr., Walker, P.L. and Wineland, M.J. 1990. A survey of Salmonella contamination in modern broiler production. J. Food Protect. 59:502.

or were a filter of the control of the

*最强的*的 1.键 100 million (100 million)

- Katsui, N., Tsuchido, T., Takano, M., and Shibasaki, I. 1981. Effect of preincubation temperature on the heat resistance of *Escherichia coli* having different fatty acid compositions. J. Gen. Microbiol. 122:357.
  - Kim, J.W., Slavik, M.F., Griffis, C.L., and Walker, J.T. 1993. Attachment of Salmonella typhimurium to skins of chicken scalded at various temperatures, J. Food Protect. 56:661.
- Mendonca, A.F., Amoroso, T.L., and Knabel, S.J. 1994. Destruction of Gramnegative foodborne pathogens by high pH involves disruption of the cytoplasmic membrane. Appl. Environ. Microbiol. 60:1555.
  - Morrison, G.J. and Fleet, G.H. 1985. Reduction of Salmonella on chick no carcasses by immersion treatments. J. Food Protect. 48:939.

graficial contrata makatik bencharan ber

- Mulder, R.W. and Bolder, N.M. 1984. Methods to reduce Salmonella contamination during processing of poultry, p. 242-248. In G.H. Snogenbos (Ed.). "Proc. Int. Symp. salmonella." American Association of Avian Pathologists, Inc. University of Pennsylvania, New Bolton Center, Kennett Square, PA.
- Murray, R.G.E., Steed, P., and Elson, H.E. 1965. The location of the mucopeptide in sections of the cell wall of *Escherichia coli* and other gram-negative bacteria. Can. J. Microbiol. 11:547.

- Sams, A.R. and R. Feria. 1991. Microbial Effects of Ultrasonication of Broiler Drumsticks Skin. J. Food Sci. 56:247.
- Shane, S.M. 1988. Update on the fate of irradiation. Poultry Proc. 4:48.
- Slavik, M.F., Kim, J., and Walker, J.T. 1994. Reduction of Salmonella and Campylobacter on chicken carcasses by changing scalding temperature.

  J. Food Protect. 58:689.
- Stern, N.J., Rothenberg, P.J., and Stone, J.M. 1985. Enumeration and reduction of Campylobacter jejuni in poultry and red meats. J. Food Protect. 48: 606.

- Thayer, D.W., Dickerson, C.Y., Rao, D.R., Boyd, G., and Chawan, C.B. 1992.

  Destruction of Salmonella typhimurium on chicken wings by gamma radiation. J. Food Sci. 57:586.
  - Tompkin, R.B. 1990. The use of HACCP in the production of meat and poultry products. J. Food Protect. 53:795.

and the transfer of the state of the part of the state of

Bankarak ing Panganah Kabupatèn Kabupatèn Kabupatèn Kabupatèn Kabupatèn Kabupatèn Kabupatèn Kabupatèn Kabupatèn

美国发展的产品的基本的一种企业的。 1912年,1912年,1912年的1912年,1912年,1912年,1912年,1912年,1912年,1912年,1912年,1912年,1912年,1912年,1912年,1

se la major di les la trasili di per cuaga cuae i di la sili di la color di la segli.

USDA. 1994. Acceptable antimicrobial treatments. Food Safety and Inspection Service Notice 49-94, Dec 21, FSIS, Washington D. C.

The first of the section of the sect

LAME GRADIENT GARAGE

TABLE 1. Recovery of S. typhimurium NAR and Campylobacter jejuni inoculated on chicken drumsticks and exposed 3 s to a radiant wall (RW) at 788°C with or without pretreatment with 1-min dip in 6% buffered sodium citrate (BSC).

<u> </u>					
Organism	Inoculum	Control	BSC	RW	BSC/RW
	(cell)				
·	0		NDB	ND	ND
	10	0.95 <sup>A</sup>	•	*C	
Salmonella	100	1.89	1.53	•	•
	1,000	2.91	2.33	0.77	
	10,000	3.94	3.77	1.76	1.55
	0	ND	ND	ND	ND
	10	ND	ND	ND	ND
C. jejuni	100	2.01	1.23	•	
	1,000	2.98	2.69	•	uřík.
	10,000	3.87	3.80	1.48	0.93

A Bacterial count is expressed as log<sub>10</sub> of numbers per cm<sup>2</sup> B ND – not done

c -\_ not detected

TABLE 2. Recovery of injured nalidixic acid resistant Salmonella typhimurium (S. typhimurium NAR) inoculated on skins of chicken drumsticks at a level of about 100 CFU and exposed to different RW temperature.

788	0/10	0/10	0/20	0/10	0/10	0/20
704	7/10	5/10	12/20	8/10	7/10	15/20
649	10/10 <sup>a</sup>	9/10	19/20	10/10	10/1 <b>0</b>	20/20
	1	2	Total	1	2	Total
RWt(°C)	Rej	olicate		Repl	icate	
DW (9C)	July	3 o storage			o storage	
	Day	s 0 storage	at 4°C	Dave	3 storage	at 4°C

<sup>&</sup>lt;sup>a</sup> First number in body of table represents number of drumsticks showing positiv for *S. typhimurium*<sup>NAR</sup>; e.g.: 10/10 indicates 10 drumsticks confirmed as positive for *S. typhimurium*<sup>NAR</sup> out of 10 drumsticks

TABLE 3: Comparison of recovery of S. typhimurium NAR and Campylobacter jejuni inoculated on chicken drumsticks and exposed 3 s to a radiant wall (RW) at 788°C with or without pretreatment with 1-min dip in 6% buffered sodium citrate (BSC).

	Log counts (mean ±SE) <sup>A</sup>			
Treatments	Salmonella typhimurium	Campylobacter jeju <b>ni</b>		
Control	7.22 ± 0.11 <sup>a</sup>	7.41 ± 0.23 <sup>a</sup>		
BSC	6.43 ± 0.51 <sup>b</sup>	5.96 ± 0.44 <sup>b</sup>		
RW	5.49 ± 0.32°	5.00± 0.12°		
BSC/RW	4.90± 0.15 <sup>d</sup>	4.05 ± 0.05d		

<sup>\*</sup>Mean values in the same column within the same microorganism that are not followed by the same letter are significantly different

TABLE 4: Effect of RW treatment on the actual number of indigenous Salmonella on chicken drumsticks skin. Cells were recovered using the rins method on whole drumsticks.

Sample number	Control (No treatment)	RW
1	6	0
2	14	0
3	0	0
4	139	26
5	2	0
6	3550	97
7	9.60 (59.50 <b>13</b> .) Nov. (6.50	
8	6	0
9	11	0.
10	0	0

#### **CHAPTER 6**

#### CONCLUSIONS

Radiant heat from a high temperature radiant wall induced microbicidal effects on surfaces of whole broilers without cooking the surface. An exposure for 5 s at 649°C with a 1-min dip in 1% buffered sodium citrate solution induced more than 1.5 log reduction in TPC. Assuming proper refrigeration is maintained during distribution and retail, RW treatment results in improved microbiological quality and potentially greater shelf-life and safety for raw poultry parts. Adding a 6% BSC solution dip before RW exposure for only 3 s at 788°C greatly increased the shelf life. Quick chilling of RW treated chicken drumsticks was ineffective on microbial quality. The epidermis on the chicken skin plays a vital role on the keeping quality. In general, when epidermis is left on the skin, the shelf life of RW treated drumsticks was increased due to better exposure of microorganisms to radiant heat facilitating their destruction. Sam combination of radiant heat and buffered sodium citrate, pH 5.8, significantly nt and all the Salar and t reduced or eliminated Gram-negative pathogens on chicken skin without causing a departure of appearance from the raw product. The treatment was effective for inoculum levels up to 1,000 CFU for both S. typhimurium and Campylobacter jejuni.

Application of radiant heat as a microbiological decontamination process for raw poultry has produced 1 - 3 log reductions of indigenous microflora and inoculated pathogens without inducing manifestation of cooking in the products.

化环点多数 化橡胶管 医水管 医水管 医皮肤管炎

Treatments which reduce salmonellae levels by 2 log units should be effectiv in controlling this pathogens, because salmonellae levels on broiler carcasses are typically < 100 CFU per carcass. Against Salmonella typhimunium and Campylobacter jejuni, our process reduced these pathogens to no recoverabl CFU from inocula of 1,000 CFU. Our main objective of extending the shelf life of raw poultry was achieved, the shelf life of RW treated poultry was double thos of controls.

Buffered sodium citrate (BSC) was effective in increasing the lethality of the radiant heat treatment, but does not have the lethal effects necessary for it to be a primary means of food preservation. BSC was a contributor to the "hurdle" approach to food preservation and food safety. Resistance of a food product to growth or survival of spoilage or pathogenic microorganisms is determined by the number of intrinsic (e.g., heat treatment) and extrinsic (e.g., storage temperature) "barriers" which act as "hurdles" for microorganisms to overcome. The more hurdles or barriers, the more difficult it becomes for a target microorganism to Things congress between the second grow or survive. In contrast to biostatic barriers which simply inhibit the growth of e grande i la la grande de la desputação de la forma de Albarda. contaminating microbes (e. g. modified atmosphere packaging), BSC can serv 图解的事实,不是是一个对于自己的一个一个一个一个一个人的人,但是是一个人的人,也是是不是一个人的人,不是是一个 as a bactericidal barrier helping to reduce the levels of potential spoilage or kan ingkaladilag ana sigli jang magali nambulo mga galanggan gang ng matakaladi at atautigi. I pathogenic microorganisms. Our studies indicate that BSC combined with radiant heat was effective for fresh poultry pasteurization to increase microbial lethality of a heat treatment thus enhancing the safety and shelf life of refrigerated poultry was in the first state of the The same of the sa products.

State Carting Control

#### **APPENDIX**

THE PROPERTY OF THE PROPERTY O

# INFRAREDITEMPERATURE MEASUREMENT ON CHICKEN DRUMSTICKS TREATED IN A RADIANT WALL OVEN

The product was a second of the second of th

egis, aparijunga kan ilah adi dalah basa indipantan jangan ban dah dalah sebesah bahasi at ilah dalah d

ng mengganggang berminal kalinggan panggang di kananggan pangganggan pengganggan berminal di kanangganggan ber

namenages) green feel at a some early to the second state state of the

an the war as well and the transport of the factors of the most of the first the first of the factors of the first of the factors of the fact

a por la la transferior de la proposició de la companya de la companya de la companya de la companya de la comp

para diakon kontra di kontra den 19. april 19. dia 17. april 19. dan 18. april 19. april 19. april 19. dan 19.

CENTRAL MANAGEMENT OF THE CONTRACT OF THE SHOP OF THE PROPERTY OF THE SHOP OF

A SECTION OF THE SECT

expression of the mesons many for expression of the expression of

the other state and the same a literal and have appeared the facility and in the well-same and

是一种技术的 唐人物的证明 斯特 的过去分词

#### **APPENDIX**

INFRARED TEMPERATURE MEASUREMENT ON CHICKEN DRUMSTICKS
TREATED IN A RADIANT WALL OVEN

#### SUMMARY

(1) [編集 智利] (4) [4] 人籍(1) (4) [4] [4]

Infrared temperature measuring devices are highly developed sensors for non-contact temperature measurement and have widespread application in industrial processing and research. This essay describes in non-mathematical term the theory upon which the measurement technology is based and its application in our process. ThermaCAM (Model PM 280, Inframetrics, Inc.), a palm-size focal plane array (FPA) radiometer with full-screen temperature measurement and built-in image storage and analysis capabilities, was used to measure the surface temperatures of chicken drumsticks exposed 3 s to a radiant wall (RW) at 788°C (1450°F). Emissivity of the chicken drumsticks with skin was determined to be 0.93 and that of skinless drumstick was 0.90. The mean surface temperature of chicken drumsticks (skin on) was increased in 3 s from 51.9 to 218.4°F. Even 10 s after the treatment, whole surface area of the drumsticks had temperature of 160°F or more. Similar treatment of skinless drumsticks could achieve an average temperature of only 161.1°F with only 50 % of the area had temperature of 160°F or more.

#### INTRODUCTION

Electromagnetic waves traveling through space may be intercepted by a suitable surface and absorbed, raising the energy level of the intercepting surface. When the electromagnetic waves have the frequency of light, the phenomenon is referred to as radiation (Toledo, 1991). All materials at temperatures higher than absolute zero (0°Kelvin) emit energy in proportion to the fourth power of their temperature. Hotter matter releases more energy than cooler matter. Like convection, radiant heat transfer is a surface phenomenon and the conditions at the surface determine the rate of heat transfer. Radiant heat transfer generally involves the range of electromagnetic waves called infrared radiation. An infrared thermometer measures temperature by detecting the infrared energy emitted by materials. The most basic design consists of a lens to focus the infrared (IR) energy on to a detector, which converts the energy to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature variation. This configuration facilitates temperature measurement from a distance without contact with the object to be measured. As such, the infrared thermometer is useful for measuring temperature under circumstances where thermocouples or other probe type sensors cannot be used or do not produce accurate data for a variety of reasons. Some of the typical circumstances are where the object to be measured is moving; where the object is surrounded by an EM field, as in induction heating; where the object is contained in a vacuum or other controlled atmosphere; or in applications where a fast response is required. Designs for an infrared

Darling (1911) discussed various concepts. However, it was not until the 1930's that the technology was available to turn these concepts into practical measuring instruments. Since that time there has been considerable evolution in the design and a large amount of measurement and application expertise has accrued. At the present time, the technique is well accepted and is widely used in industry and in research.

Then the factorial property is the control of

### Measurement Principles

Infrared radiation is part of the Electromagnetic Spectrum and occupies frequencies between visible light and radio waves. The IR part of the spectrum spans wavelengths from 0.7 micrometers to 1000 micrometers (microns) as shown in Figure 1. Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement. This is because the IR detectors currently available to industry are not sensitive enough to detect the very small amounts of energy available at wavelengths beyond 20 microns.

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects, which are opaque to the human eye, part of the IR energy striking the

object surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a proportion will be re-emitted and part will be reflected internally. This will also apply to materials, which are transparent to the eye, such as glass, gases and thin, clear plastics, but in addition, some of the IR energy will also pass through the object (Figure 2). These phenomena collectively contribute to what is referred to as the *emissivity* of the object or material.

Materials which do not reflect or transmit any IR energy are know as Blackbodies and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0, which can be achieved in real life is an IR opaque, spherical cavity with a small tubular entry (Figure 3). The inner surface of such a sphere will have an emissivity of 0.998. Different kinds of materials and gases have different emissivities, and will therefore emit IR at different intensities for a given temperature. The emissivity of a material or gas is a function of its molecular structure and surface characteristics. It is not generally a function of color unless the source of the color is a radically different substance to the main body of material. A practical example of this is metallic paints, which incorporate significant amounts of aluminum. Most paints have the same emissivity irrespective of color, but aluminum has a very different emissivity, which will therefore modify the emissivity of metallized paints.

Just as is the case with visible light, the more highly polished some surfaces are, the more IR energy the surface will reflect. The surface characteristics of a material will therefore also influence its emissivity. In

temperature measurement this is most significant in the case of infrared opaque materials which have an inherently low emissivity. Thus a highly polished piece of stainless steel will have a much lower emissivity than the same piece with a rough, machined surface. This is because the grooves created by the machining prevent as much of the IR energy from being reflected. In addition to molecular structure and surface condition, a third factor affecting the apparent emissivity of a material or gas is the wavelength sensitivity of the sensor, known as th sensor's spectral response.

### Theoretical Basis for IR Temperature Measurement

The formulas upon which infrared temperature measurement is based are old, established and well proven. It is unlikely that most IRT users will need to make use of the formulas, but knowledge of them will provide an appreciation of the interdependency of certain variables, and serve to clarify the foregoing text.

The important formulas are as follows:

Markey and the few of the same of the same to be a facility to be a facility of the same of

### The state of the s

When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.

# (Grand 2: Stephan Boltzmann Law )) 中国的 (Grant Edge) (Grant Edge) (Grant Edge)

The hotter an object becomes the more infrared energy it emits:

## maka a **3. Wien's Displacement Law**alfor reports a lawa a

The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

### 4. Planck's Equation

Describes the relationship between spectral emissivity, temperature and radiant energy.

The result of the second of th

# Infrared Thermometer Design and Construction

A basic infrared thermometer (IRT) design, comprises a lens to collect the energy emitted by the target; a detector to convert the energy to an electrical signal; an emissivity adjustment to match the IRT calibration to the emitting characteristics of the object being measured; and an ambient temperature compensation circuit to ensure that temperature variations within the IRT, due to ambient changes, are not transferred to the final output. The modern IRT is founded on this concept (Fig. 4), but is more technologically sophisticated to widen the scope of its application. Probably the most important advance in infrared thermometry has been the introduction of selective filtering of the incoming IR signal, which has been made possible by the availability of more sensitive detectors and more stable signal amplifiers. Whereas the early IRT's required a broad spectral band of IR to obtain a workable detector output, modern IRT's routinely have spectral responses of only 1 micron. The need to have selected and narrow spectral responses arises because it is often necessary to either see through some form of atmospheric or other interference in the sight path, or in fact to obtain a measurement of a gas or other substance which is transparent to a broad band of IR energy. Some common examples of selective spectral responses are 8-14 microns, which avoids interference from

atmospheric moisture over long path measurements; 7.9 microns which is used for the measurement of some thin film plastics; and 3.86 microns which avoids interference from CO<sub>2</sub> and H<sub>2</sub>O vapor in flames and combustion gases. The choice between a shorter, or longer wavelength spectral response is also dictated by the temperature range because, as Planck's Equation shows, the peak energy shifts towards shorter wavelengths as the temperature increases (Planck, 1959). Applications, which do not demand selective filtering for the above stated reasons, may often benefit from a narrow spectral response as close to 0.7 microns as possible. This is because the effective emissivity of a material is highest at shorter wavelengths and the accuracy of sensors with narrow spectral responses is less affected by changes in target surface emissivity.

temperature measurement. Unless the emissivity of the material being measured is known, and incorporated into the measurement, it is unlikely that accurate data will be obtained. There are two methods for obtaining the emissivity of a material:

a) by referring to published tables and b) by comparing the IRT measurement with a simultaneous measurement obtained by a thermocouple or resistance thermometer and adjusting the emissivity setting until the IRT reads the same. Fortunately, the published data available from the IRT manufacturers and some research organizations is extensive, so it is seldom necessary to experiment. As a rule of thumb, most opaque, non-metallic materials have a high and stable emissivity in the 0.85 to 9.0 range; and most un-oxidized, metallic materials have

a low to medium emissivity from 0.2 to 0.5, with the exception of gold, silv r and aluminum which have emissivities in the order of 0.02 to 0.04 and are, as a result, very difficult to measure with an IRT. While it is almost always possible to establish the emissivity of the basic material being measured, a complication arises in the case of materials, which have emissivities that change with temperature such as most metals, and other materials such as silicon and high purity, single crystal ceramics. Some applications, which exhibit this phenomenon, can be solved using the two-color ratio method (Sparrow and Cess, 1966). This technique is not dissimilar to the infrared thermometers described so far, but measures the ratio of infrared energy emitted from th material at two wavelengths, rather than the absolute energy at one wavelength or wave band.

# Temperature measurement of chicken drumsticks

Fresh (not previously frozen) chicken drumsticks with skin from the same producer were obtained from a local supermarket 1-2 hours before treatments. They were divided in two groups. One group was exposed to 3s radiant heat at 1450 °F RW temperature. The second group was similarly treated, but only after removing the skin. Surface temperature of the drumsticks was measured by taking images of drumsticks at various processing stages by a palm-sized focal plane array radiometer (ThermaCAM PM 280) supplied by Inframetrics, Inc., North Billerica, MA (Fig. 5). ThermaCAM uses a 256 X 256 platinum silicide focal plane array (FPA) detector, which provides a superior image without the

use of mechanical scanning. An integrated closed-cycle cryogenic cooler maintains the detector temperature. Images are displayed on a color viewfinder, and can be output as standard video or S-Video. Data can be stored on removable solid-state PCMCIA memory cards. Calibrated IR data is output as TV and VCR-compatible video for extensive real-time data analysis. Data analysis was performed by ThermaGRAM95® windows-based software program manufactured by ThermaGRAM95® windows-based software program software performs real-time analysis on live or stored images. ThermaCAM transfers live images to ThermaGRAM via the TGRAM output port. Static images can be transferred to ThermaGRAM via the PCMCIA ImageBank memory card.

In order to measure the surface temperature we first tried to measure with an infrared gun Raynger II plus made by Raytek, CA, This portable instrument (Fig. 6) measures surface temperature without contact. The instrument collects the infrared energy radiated by a target and computes its surface temperature. But because our sample was being processed at high speed (64.8 ft/sec) we were not able to shoot the gun on the sample. Even if we were successful, the high wall temperature would have generated so much background noise that it would not give an accurate measurement.

Later, we experimented with temperature indicating liquid. OMEGALAQ

Temperature Indicating Liquids consist of a temperature melt material in a liquid

form. They are used to tell temperatures on surfaces and are widely used for

monitoring critical temperatures in electronics field, such as preheat

temperatures for wave soldering. Other applications include electric heatsealing.

postforming plastic laminate, and annealing polished metal surfaces. These liquids have a time response on the order of milliseconds (0.001 sec). Heating to a temperature well above the melting point, these liquids are subject to some sublimation. We used liquids for 182, 188, 194, and 200°F on chicken drumsticks (Fig. 7). These were good indicators and we got melting of all these liquid, indicating that our process raised the temperature of the drumsticks above 200 °F. The problem with these liquids were that the evaluations were subjective. And also it was difficult to use these liquids on a wet surface like chicken drumsticks.

Finally, we went for hi-tech measurement with ThermaCAM and Fig. 8 14 represents actual images and histograms of temperature measurment of chicken drumsticks. Table. 1 presents the change in surface temperature over time of fresh skin-on chicken drumsticks treated by RWO. To evaluate the efficacy of our process, we set a cutoff temperature of 160°F (USDA/FSIS recommended temperature for Salmonella elimination) above which we need to keep our sample for sufficient time to eliminate pathogens like salmonella. Our analysis showed that initially the drumsticks received sufficient heat. Because of the biological nature of the drumsticks we did not get a uniform temperature over the drumstick surface. Cooler spots were observed on areas of bare skin and hotter spots were observed on areas with high fat content. The unequal temperature distribution could also be due to unequal distances from the radiant wall. This can be controlled by changing the design of the wall configuration. As for biological factor, if we use uniform drumsticks from a single flock, it can be minimized. However, it is not the uniformity of temperature that will determine the

efficacy of our process, rather the lowest temperature on the drumsticks should be high enough to kill the organism. We can hypothesize, that on the areas that did not receive/hold sufficiently our selected temperature, the organisms will be sub-lethally injured and will require optimum environmental conditions to enable repair of sub-lethal damage. For this reason, the combined effect of treatment with radiant heat in conjunction with other modes of preservations can be used to achieve low populations of viable cells initially and control growth during storag.

When the effect of radiant heat on skinless drumsticks compared to drumsticks with skin were analyzed, we found the skinless drumsticks received significantly less heat than their skin-on counterparts (Table 2). This could be due to evaporative cooling of the wet skinless tissue at high temperature. However, unless a detailed microbiological study is carried out, it is difficult to see the implications of these lower temperatures. Skin tissues and muscle tissues have different properties that might influence the destruction/survival of the microorganisms.

# REFERENCES NO DESTRUCTION OF THE REFERENCES NO DESTRUCTION OF THE RESERVENCES.

ALITY CONTRACTOR OF THE TAXABLE OF THE CONTRACTOR AND THE

- Toledo, R.T. (1991). Fundamentals of Food Process Engineering ( 2<sup>nd</sup> ed.).
  Chapman and Hall, New York.
  - Darling, Charles R.; Pyrometry. A Practical Treatise on the Measurement of High Temperatures. Published by E.& F.N. Spon Ltd. London. 1911.
  - Planck, M. 1959. The theory of heat radiation. Dover publication, New York.

in Section

Sparrow, E. M. and R. D. Cess. 1966. Radiation heat transfer. Brooks/ Cole Publishing M Company, CA.

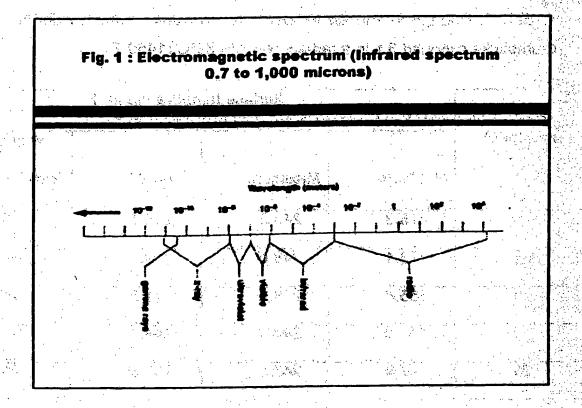
1.00

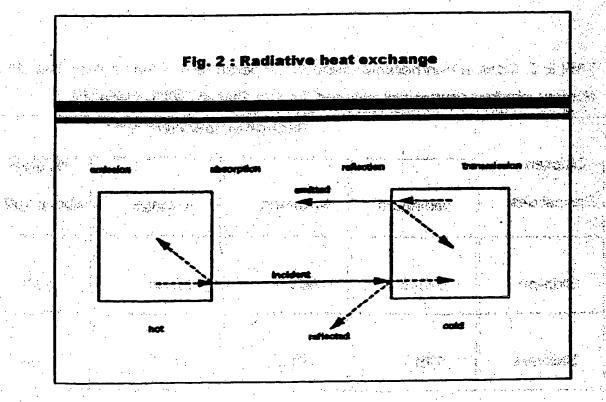
TABLE 1. Change in surface temperature over time of fresh skin-on chicken drumsticks exposed 3 s to a radiant wall at 788°C (1450°F)

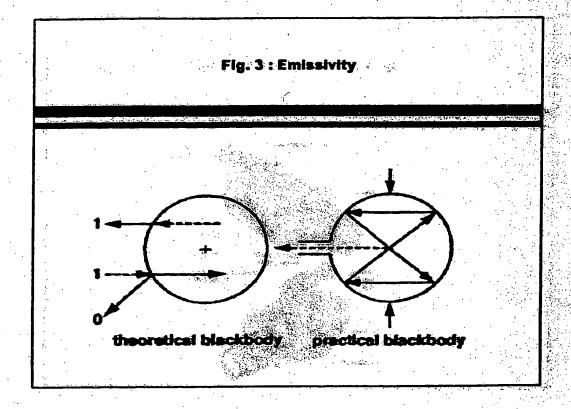
		Surface temperature in °F				
Time (sec)				% area		
	Minimum	Maximum	Average	above 160°F		
0	175.3	248.0	218.4	100		
5	173.1	248.0	209.4	100		
10	165.4	248.0	199.5	100		
15	114.5	248.0	144.4	21		
20	97.8	248.0	136.3	15		

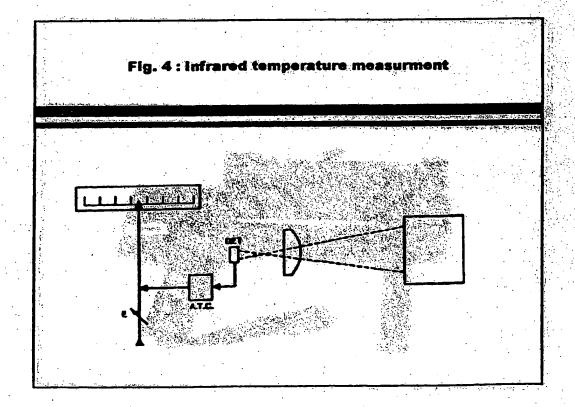
TABLE 2. Comparison between surface temperature profiles of fresh skin-on and skinless chicken drumsticks exposed 3 s to a RW at 788°C (1450°F)

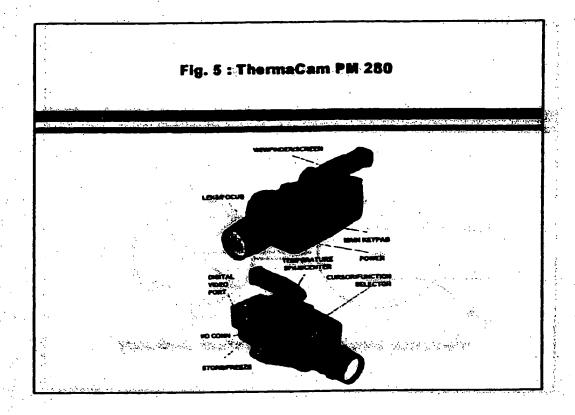
×	Surface temperature in °F					
Chicken	approximately manager	erikojaji Propinski		% area		
Drumsticks	Minimum	Maximum	Average	above 160°F		
			The state of the s			
Skin-on	175.3	248.0	218.4	100		
	· Progr	1		.· ?		
Skinles <b>s</b>	116.7	248.0	161.1	49		

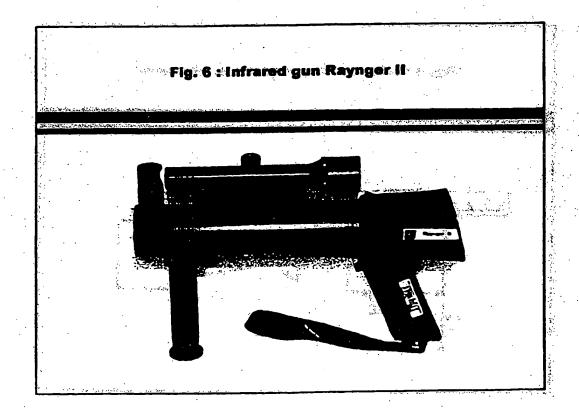


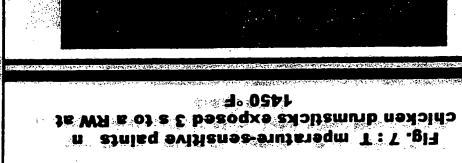




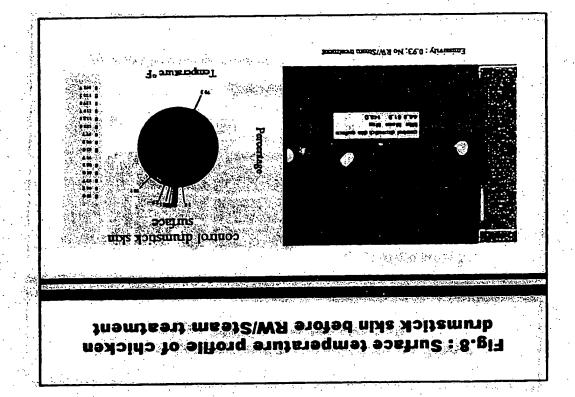


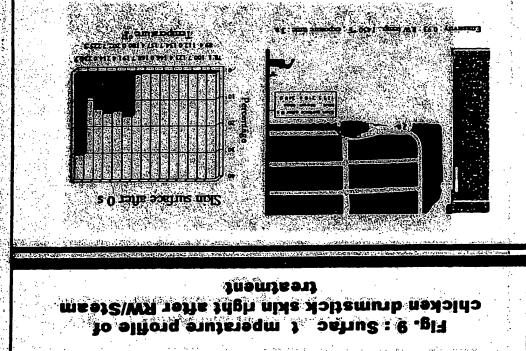












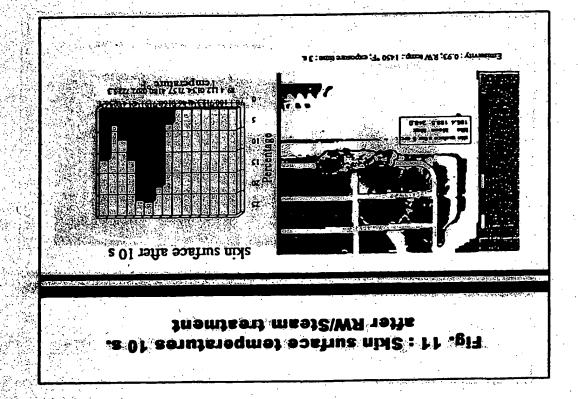


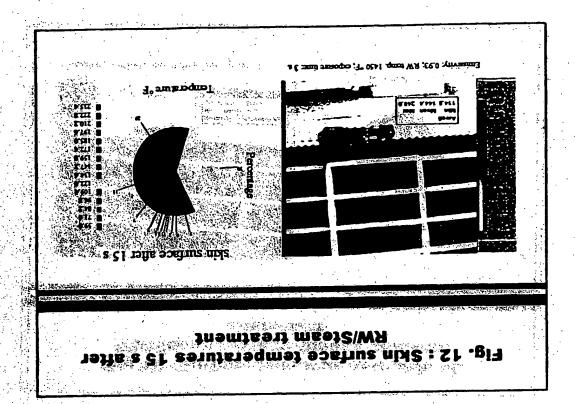
Inemisari mset (WA 1911s. Fig. (0: Skin surface temperatures 5 sec

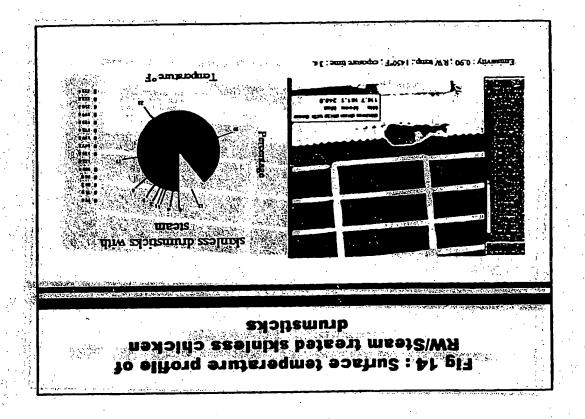
skin surface after 5 s

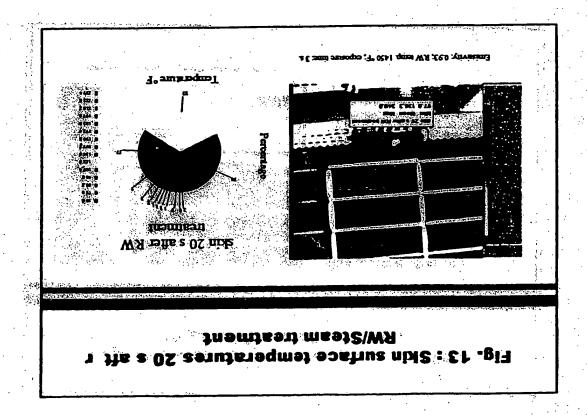
A C: Some washing : 0.93; R.W temper 1.50 °F; capairing time : 3 a.

के राष्ट्रार करानी प्राप्त में अध्यक्षित्रकार की रहते हुई अहा है है है









# Extended Shelf Life Refrigerated Foods:

Microbiological Quality and Safety

This Scientific Status

Summary addresses microbiological concerns and control methods for ensuring safety and quality of these foods.

A PUBLICATION OF
THE INSTITUTE OF FOOD TECHNOLOGISTS'
EXPERT PANEL ON FOOD SAFETY AND NUTRITION

upermarket shelves today need to cater to the gourmet cook as well as the timeharried parent. Increasingly all types of consumers are demanding minimally-processed foods that are high in quality, nutritionally superior, and easy to prepare. Food processors have met this demand by developing refrigerated foods with extended shelf life. Ready-to-eat luncheon meats and complete heat-and-eat meals are some examples. By their very nature, however, these foods present challenges to ensure microbiological quality and safety. This Scientific Status Summary addresses the microbiological concerns associated with extended shelf life refrigerated foods and control measures for ensuring microbiological quality and safety.

Extended shelf life refrigerated foods are foods that have received minimal processing or precooking and have an enhanced but limited shelf life; refrigeration is a key preservation measure. These foods include conventional products, such as luncheon meats and cured meats, as well as a new generation of partially processed refrigerated foods (NFPA, 1988) such as meat, seafood, egg, and vegetable salads, fresh pasta and pasta sauces, other sauces, soups, entrees, complete meals, and uncured meat and poultry items. Sous-vide foods, cooked inside a hermetically sealed plastic package under vacuum, are also included in this definiti n. If extended shelf life refrigerated foods are heat processed, the heat treatment is much less than that required for commercial sterility. Canned foods are, therefore, excluded from this food category. Sous-vide foods and others that receive a l wer heat treatment than that used f r

canning and that require refrigeration are described by some authors as "refrigerated processed foods of extended durability" (Peck, 1997).

#### **Microbiological Concerns**

The chief microbiological concerns associated with these products center around two types of microorganisms—psychrotrophic and mesophilic pathogens-that could grow during extended refrigerated storage or temperature abuse. Psychrotrophs are bacteria, yeasts, and molds that grow, although slowly, at refrigeration temperatures (below 7°C) but grow optimally at temperatures above refrigeration, e.g., 25-30°C. Their maximum growth temperatures are 30-35°C (Kraft, 1992; Olson and Nottingham, 1980). Mesophilic pathogens could survive under refrigeration and grow during any temperature abuse of the food. Mesophiles grow well between 20-45°C with optimum growth between 30-40°C (Jay, 1992). The potential for psychrotrophic spoilage microorganisms to grow during the extended refrigerated storage period and decrease organoleptic quality or spoil the food product is also a concern.

Pathogenic Microorganisms. Conventional wisdom of decades ago held that properly refrigerated foods would remain safe because it was thought that pathogenic bacteria could not grow at refrigeration temperatures. Microbial growth was thought necessary to either produce a sufficient number of cells or enough toxin to cause foodborne illness. Since then, scientists have learned that several pathogens—such as Aeromonas hydrophila, nonproteolytic strains of Clostridium botulinum, Listeria spp., Yersinia enterocolitica, some strains of Bacillus cereus, enteropathogenic Escherichia coli, and Vibrio parahaemolyticus—can grow at refrigerati n temperatures. Furthermore, scientists now know that some pathogens can cause illness when nly a few cells are ingested. F r example, as few as ten cells f the extremely virulent E. coli O157:H7 may cause hemorrhagic

**ELMER H. MARTH** 



# Extended Shelf Life

ONTINUED

colitis (Buchanan and Doyle, 1997). Readers may refer to several texts (Cliver, 1990; Doyle et al., 1997; FDA, 1992; ICMSF, 1996; Jay, 1996) for detailed information on the characteristics of pathogenic microorganisms and the foodborne illnesses they cause.

A. hydrophila is a facultative anaerobe that is generally considered a ubiquitous waterborne microorganism, occurring widely in fresh and brackish waters. Recent surveys (Pin et al., 1994; Saad et al., 1995; Schweizer et al., 1995) detected A. hydrophila in samples of raw milk, poultry, lamb, cheese, shellfish, pork, beef, watercress, lettuce, and escarole. Most cases of illness attributed to A. hydrophila have been sporadic, rather than associated with an utbreak (FDA, 1992).

C. botulinum is a ubiquitous anaerobic spore-forming bacterium whose spores are widely distributed in soil, freshwater and marine environments, raw agricultural products, and the intestinal tracts of fish and animals (Sugiyama, 1990). Four groups of C. botulinum (I-IV) and some strains of Clostridium baratti and Clostridium butyricum can produce botulinum neurotoxin (Hatheway, 1992). C. botulinum type I (proteolytic strains) and C. botulinum type II (nonproteolytic strains) are responsible for human foodborne botulism (Peck, 1997). The botulinum neurotoxins are differentiated as types A through G on the basis of serological reaction. The nonproteolytic strains—type E and some type B and F—do not produce overt signs of food spoilage during growth and toxin production.

Some nonproteolytic strains of *C. botu-linum* are a concern with extended shelf life refrigerated foods because with sufficient time they may be able to grow and produce neurotoxin at temperatures as low as 3.3°C. Proteolytic strains, which are mesophilic, may be able to grow and produce toxin in foods if temperature abuse occurs. Most outbreaks of botulism in the United States have been caused by home-processed vegetables, fish, or meat products (ICMSF, 1996). The incidence f botulism from consumption of refrigerated foods is exceedingly low. However, the few outbreaks

that have occurred and research challenge studies illustrate the potential *C.* botulinum hazards associated with extended shelf life refrigerated foods (Conner et al., 1989).

L. monocytogenes, a facultative anaerobe, is ubiquitous in the environment. L monocytogenes has been isolated from soil, silage, food processing environments, and healthy humans and animals (ICMSF, 1996). A variety of foods, such as refrigerated ready-to-eat meat sandwiches and meat salads have been recalled from the marketplace because of contamination with L. monocytogenes (Ryser and Marth, 1991). Individuals with compromised immune systems, e.g., newborns, the elderly, and people suffering from the acquired immunodeficiency syndrome, are most susceptible to listeriosis. Outbreaks of listeriosis in North America have been associated with coleslaw, soft Mexican-style cheese, and milk (McLauchlin, 1996).

Y. enterocolitica is a facultative anaerobe whose main reservoir of bioserotypes pathogenic to humans is believed to be the pig (ICMSF, 1996). Symptoms of yersiniosis, the disease caused by Y. enterocolitica, may include fever, diarrhea, headache, vomiting, and severe abdominal pain similar to that associated with appendicitis. Y. enterocolitica has been isolated from a variety of animals, foods (lamb, pork, oysters, shrimp, and crabs), and water (Doyle and Cliver, 1990; ICMSF, 1996); however, isolates are often avirulent. Outbreaks of yersiniosis, which are relatively uncommon in the United States, have been caused by contaminated chocolate milk, recontaminated pasteurized milk, bean sprouts, tofu, and chitterlings (raw pork intestine).

B. cereus, an aerobic spore-former including psychrotrophic and mesophilic strains, is widely distributed in nature and in foods. B. cereus is commonly found in soil, milk, cereals, starches, herbs, spices, and other dried food products and on the surfaces of meats and poultry. B. cereus can produce two toxins that cause two distinct types of illness-a diarrheal illness and an emetic illness characterized by nausea and vomiting. Every well-documented report of B. cereus intoxication has described time and temperature abuse that enabled initially relatively low (inn cuous) levels f B. cereus in foods to increase greatly. In most incidents, the food vehicle was a cereal or cereal- or

spice-containing product (ICMSF, 1996).

A few serotypes and strains of E. coli, a facultative anaerobe that is part of the normal microflora of the intestinal tract of humans and most warm-blooded animals, can cause illness. Although they are not considered true psychrotrophs, some of these strains can grow at 6.9°C and below (Kraft, 1992; Palumbo et al., 1994). Pathogenic E. coli are categorized into six groups-enteropathogenic, enteroinvasive, enterotoxigenic, enterohemorrhagic (EHEC), enteroaggregative, and diffusely adherent (Buchanan and Doyle, 1997). Foods involved in outbreaks caused by pathogenic E. coli include meat, poultry, fish, vegetables, apple cider, raw milk, Brie and Camembert cheese, water, and radish and alfalfa sprouts. Some strains of E. coli, including some EHEC strains, are acid tolerant, a complex phenomenon that is growth phase dependent and inducible; acid tolerance may persist for extended periods at refrigeration (Buchanan and Doyle, 1997).

V. parahaemolyticus is a facultatively anaerobic halophile (requiring sodium chloride for growth) occurring worldwide in inshore marine waters and frequently associated with molluscs, crustaceans, and fish (ICMSF, 1996). Although the microorganism is considered mesophilic, growth has been demonstrated at temperatures as low as 5°C (Twedt, 1989). The microorganism is the most common cause of foodborne illness in Japan because it frequently contaminates seafood, often eaten raw in that country. Contaminated raw, improperly cooked, and cooked recontaminated fish and shellfish have been implicated in cases of gastroenteritis.

Spoilage Microorganisms. With sufficient time at refrigeration temperatures, several types of psychrotrophic bacteria, yeasts, and molds may grow to levels sufficient to cause food spoilage. These microorganisms include the Acinetobacter-Moraxella group, Alcaligenes species, Flavobacterium spp., Microbacterium spp., Xanthomonas spp., and the microorganisms of primary concern in extended shelf life refrigerated foods: Brochothrix thermosphacta, lactic acid bacteria (LAB), and Pseudomonas spp.

B. thermosphacta, which is aerobic (requiring free oxygen) to facultatively anaerobic (growing well either aerobically or anaerobically), has been recovered from vacuum-packaged beef, pork, lamb, and heat-processed cured meats such as sliced cooked ham, corned beef, and others (Kraft, 1992). The extent of spoilage of

vacuum-packed meat by B. thermosphacta varies with product pH and with oxygen permeability of the packaging material (Egan and Grau, 1981). Spoilage may involve devel pment of sliminess and production of off-od rs and off-flavors conferred by short chain fatty acids (Jay, 1992).

The LAB, such as Lactobacillus spp., Leuconostoc, and Pediococcus, are facultatively anaerobic. The type of spoilage produced by the LAB is determined by the nature of the bacteria. Homofermentative LAB produce primarily lactic acid during sugar fermentation. Heterofermentative LAB produce acetic and formic acid, ethanol, and carbon dioxide, in addition to lactic acid. LAB can spoil a variety of foods, including milk and milk products, meats, vegetables, fruit juices, sugary products, alcoholic beverages, and products preserved with vinegar (Sharpe and Pettipher, 1983).

are among the most common spoilage agents of refrigerated foods (Gill, 1986; Greer, 1989; Kraft, 1986; Splittstoesser, 1976). Growth of Pseudomonas spp., like that of other Gram-negative psychrotrophs, is affected by oxygen tension, salt and ther food additives, water activity (a.). pH, and other factors. During growth, pseudomonads produce proteases and lipases that can catalyze reactions causing degradation of protein and fat. The consequence of these reactions is formation

of peptides and fatty acids of undesirable

flavor (e.g., bitterness, rancidity) and

Pseudomonas spp., which are aerobic,

odor. Sometimes these bacteria also produce unsightly green pigments.

Many yeasts and molds given sufficient time under refrigeration temperatures can spoil fruit juices, meat products. vegetables, dairy products, and possibly ther foods (Jay, 1987; Splittstoesser, 1987). Some yeasts in the genera Candida, Hansenlaspora, and Saccharomyces can grow in fruit juices at -5.5°C to -2.2°C, just above the freezing temperature for these foods (Pederson et al., 1959). Several genera of yeasts are found on fish and meat products. These include Candida, Cryptococcus, Debaromyces, Hansenula, Pichia, Rhodotorula, Saccharomyces, Sporobolomyces, Torula, Torulopsis, and Trichospora (Jay, 1987). Growth of yeasts on foods is commonly accompanied by production f carbon dioxide and yeasty, fruity, or alcoholic off-flavors and odors.

Psychrotrophic m lds include Botrytis cinerea, Geotrichium candidum, Pullaria pullulans (Aureobasidium pullulans), and some species in the genera Alternaria,

Monilia, Mucor, Penicillium, Sporotrichium, and Rhizopus. Not only does the visible presence of mold indicate spoilage, m lds also commonly produce enzymes that degrade carbohydrates, fats, and proteins, causing softening of foods and flavor and aroma deterioration. Some species of molds, especially those in the genera Aspergillus, Fusarium, and Penicillium, can produce mycotoxins. Aspergillus spp. cannot produce mycotoxins at refrigeration temperatures, whereas certain species of Fusarium and Penicillium can (Frisvad and Samson, 1991).

#### Control Measures

Several types of control methods are effective in preventing or minimizing microbial contamination of product and inhibiting the growth of or destroying microbial contaminants.

**Good Manufacturing Practices** (GMPs), Sanitation, and Hygiene. Processors need to select high-quality raw materials with low levels of microorganisms, especially psychrotrophs. They need to determine potential microbiological hazards of ingredients, possibly using microbiological specifications for ingredients to minimize risk (Moberg, 1989).

Fabrication of raw materials into finished products under hygienic conditions is also important. Food processing equipment must be designed and constructed so that it: (1) is inert to the product, (2) has smooth and nonporous product-contact surfaces, (3) is readily accessible for cleaning and inspection, (4) is self-emptying or self-draining, (5) has covers to prevent external contamination, and (6) has readily cleanable surfaces that do not contact the product and do not harbor contaminants (Cliver and Marth, 1990). The equipment should be cleaned and sanitized as often as is necessary during a day's operation to prevent development of a biofilm that can contaminate subsequent lots of product. Cleaning and sanitizing adequacy can be determined using the more traditional swab procedures, the RODAC (agar contact) method, or the newer rapid ATP (adenosine triphosphate) bioluminescence assays.

Filtration of air entering the food processing area reduces the number of airborne contaminants. If processed foods will not receive a heat treatment or will have few barriers to microbial growth, use of "absolute" (high efficiency) air filters can virtually eliminate microbial contaminati n. If an air conditioning system is present, the system must be maintained properly so that condensate drains freely and does not contaminate the product. Food processing personnel must use hygienic practices and must be barred from moving from areas containing raw materials to areas containing finished products.

GMPs, sanitation, and hygiene are necessary prerequisites for implementing an effective Hazard Analysis Critical Control Point (HACCP) system, which enables the highest level of food safety assurance possible. HACCP is a systematic approach to the identification, evaluation, and control of food safety hazards, from raw material production and procurement to distribution and consumption of the finished product (NAC-MCF, 1997). HACCP is based on seven principles: (1) conduct a hazard analysis, (2) determine the critical control points, (3) establish critical limits, (4) establish monitoring procedures, (5) establish corrective actions, (6) establish verification procedures, and (7) establish recordkeeping and documentation procedures.

Multiple Barriers/Hurdles. Referred to as the hurdle concept or hurdle technology (Leistner and Gorris, 1995; Scott, 1989), this approach combines several factors at subinhibitory concentrations that can effectively control microorganisms in refrigerated foods. Common hurdles include physical elements-such as refrigeration, modified atmosphere packaging (MAP), and heat treatmentand physicochemical factors—such as a,, pH, and preservatives. When used together, hurdles interact, sometimes synergistically, enabling use of lower intensities of each factor than would be necessarv if each were used alone.

Scott (1989) recommended that challenge studies be conducted to verify the effectiveness of the combination of hurdies. For example, Simpson et al. (1995) demonstrated the antibotulinal effects of salt and pH in minimally processed sous vide spaghetti and meat sauce on proteolytic C. botulinum types A and B spores and toxin production. The challenge studies indicated that the probability of toxigenesis increased with storage time, but that it decreased as either the a\_ or pH was decreased. Growth of the spores and toxin production were prevented in the product that was processed at 75°C for 36 min and held at 15°C (simulating mild temperature abuse) for 42 days by >1.5% salt (a\_0.983) and pH 5.5.

Ingredients. Some products can be

# Extended Shelf Life

ONTINUED

formulated with ingredients that are barriers to microbial growth. For example, rganic acids, particularly acetic but also lactic and citric, can inhibit bacterial growth (Ahamad and Marth, 1989; El-Shenawy and Marth, 1989a; Park et al., 1970). Sorbate, propionate, and benzoate have both antibacterial and antifungal properties (El-Shenawy and Marth, 1988 a,b; El-Shenawy and Marth, 1989a,b; Park and Marth, 1972; Ryser and Marth, 1988). Although salt has antimicrobial properties it is not commonly used in high enough concentrations to be effective; this is particularly true of "low-sodium" foods. When appropriate, use of salt and other ingredients to reduce the a, t 0.980 or below will lengthen the lag phase of most bacteria and will further reduce the rate of any subsequent growth (Cliver and Marth, 1990).

Heat Treatment. Heating foods will reduce the microbial population; the degree of reduction depends on the magnitude of the heat treatment, i.e., time and temperature. The magnitude of heat treatments commonly used is pasteurizing (destructive to vegetative pathogens) rather than sterilizing. Heat treatments lower than those producing commercial sterility are likely to inactivate vegetative cells, but not bacterial spores. Once the heating is completed, stringent hygienic measures must be implemented to pre-

Table 1 Generation times of psychrotrophic Pseudomonas species during growth in food. Adapted from Snyder (1996).

			•
Temperature ° C ° F		Generation time (h)	Food
0	32	26.6	Dairy product
0	32	30.2	Fish
2.5	36.5	7.7	Dairy product
2.5	36.5	8.0	Chicken
2.5	36.5	13.8	Meat
4.5	40	11.7	Dairy product
4.5	40	6.7	Fish
4.5	40	5.0	Dairy product
10	50	5.4	Dairy product
10	50	2.6	Dairy product
10	50	2.7	Chicken
10	50	1.9	Fish

vent recontamination of the food with psychrotrophic spoilage r pathogenic microbes.

Modified Atmosphere Packaging. MAP extends product shelf life by reducing oxygen and/or increasing gases, such as carbon dioxide, in the food product environment. MAP inhibits the growth of aerobic spoilage microorganisms, such as *Pseudomonas* species, but allows facultative anaerobes such as LAB to grow. Integrated with aseptic packaging, the technology has experienced rapid growth in the minimally processed refrigerated foods sector (Brody, 1996).

Use of MAP is not without some risk, however. Any facultatively anaerobic or anaerobic psychrotrophic pathogens, such as nonproteolytic C. botulinum type E or Y. enterocolitica, may be able to grow until the LAB have reduced the pH of the product to inhibitory levels. Further, unlike aerobic spoilage microorganisms, growth of LAB may not be accompanied by overt evidence of spoilage. Moreover, if the MAP product received a nonsterilizing heat treatment, any surviving C. botulinum spores may, upon temperature abuse of the product, germinate, grow, and produce toxin without organoleptic signs of spoilage.

Storage Temperature and Shelf life. Microbial lag phases (during which there is no growth or a decline in microbial numbers) and generation times (duration between formation of a daughter cell and its division into two new cells) increase as refrigeration temperature decreases (Table 1, 2, and 3). Thus, product temperature should be maintained just slightly above freezing. Acceptable product shelf life (e.g., days or weeks) at specified temperature limits should be established and monitored to help manage food quality and safety. Because the potential exists for temperature abuse at some point during handling or for storage past the intended shelf life, timetemperature indicators or integrators can be useful in determining when refrigeration temperatures or intended storage times have been exceeded (Labuza, 1996; Taoukis et al., 1991).

Other Control Measures. Table 4 lists potential n n-thermal methods t extend shelf life and their mode of actinn microbial cells. Except for the limited use of food irradiation, the bacteriocinnisin, and high hydrostatic pressure (HHP), these methods are not yet fully developed nor commercially applied.

Table 2 Lag time and generation time of Listeria monocytogenes in fluid dairy products at various temperatures. Adapted from Rosenow and Marth (1987).

Temperature °C	Lag time (h)	Generation time (h)
4	120-144	33.3-36.3
8	24-48	10.6-13.1
· 13	10	5.8-6.0
21	. 2	1.7-1.9

Ionizing radiation, from gamma rays (produced by the radioisotopes cobalt-60 or cesium-137), machine generated x-rays (with a minimum energy of 5 million electron volts, MeV), and electrons (with a maximum energy of 10 MeV) has been studied extensively. The United States has accepted this nonthermal processing technology for insect disinfestation of wheat, wheat flour, and fresh fruits and vegetables, inhibition of maturation of fresh fruits and vegetables, sprout inhibition of potatoes, inactivation of Trichinella spiralis in pork, and microbial decontamination of spices, herbs, vegetable seasonings, poultry, and red meats. Commercial application of ionizing radiation to foods in the United States, however, has grown slowly (Olson, 1998). Widespread application to refrigerated foods requires consumer acceptance.

Pulsed electric fields technology (PEF), also nonthermal, uses very short pulses of high intensity electric fields to inactive microorganisms. It has been largely limited to liquids such as juices, milk, and liquid egg. Applied to foods, PEF has the potential to equal conventional pasteurization (Yousef, 1996).

Pulsed high-intensity light is a nonthermal technology that uses a xenon flashlamp to generate extremely brief (< 2 msec) flashes of intense broad-spectrum (200 to 1,100 nanometer wavelength) light to inactivate microorganisms (Yousef, 1996). Accepted by the Food and Drug Administration (FDA, 1996) for controlling microorganisms on the surface of food, the technology is also useful for treating surfaces of equipment and packaging materials. Successful commercial application to food requires further development because the method as currently understood suffers from limited penetration int food and may cause lipid oxidation (Y usef, 1996).

HHP is effective in controlling microorganisms. Raffalli et al. (1994) demonstrated that *L. innocua* added to 35% fat cream at 10<sup>7</sup> cells per milliliter was re-

duced 98.7-99.99% after treatment at 25-26°C for 10-30 min. The D-value for L. innocua was 7.4 minutes. After treatment for 20 and 30 min, all surviving micro rganisms were injured; a resuscitation step was needed bef re they were able to grow on a selective medium. HHP is applied commercially to refrigerated avocado products.

Bacteriocins are antimicrobial proteins produced by certain bacteria. The best known bacteriocin is nisin (also designated as a lantibiotic), produced by certain strains of Lactococcus lactis subsp. lactis (formerly Streptococcus lactis). In the United States, nisin is generally recognized as safe (GRAS) for limited use in pasteurized processed cheese to control growth of and toxin production by C. botulinum (FDA, 1988). GRAS petitions have been filed for use of nisin in reduced cholesterol liquid whole eggs. sauces, and nonstandardized salad dressings (FDA, 1994, 1995). In recent years, an array of other bacteriocins, many of which are inhibitory to foodborne pathogens, has been discovered. These include unnamed bacteriocins produced by enterococci (Martin et al., 1994; Tarelli et al., 1994), pediocin produced by Pedicoccus acidilactici (Huang et al., 1994), bavaricin produced by Lactobacillus bavaricus (Larsen and Norrung, 1993), mesenterocin produced by Leuconostoc mesenteroides (Huang et al., 1993; Maftah et al.,

1993), carnocin produced by Carnobacterium piscicola (Bagi and Buchanan, 1994; Mathieu et al., 1994), sakacin produced by Lactobacillus sake (Holck et al., 1994), and curvaticin produced by Lactobacillus curvatus (Garver and Muriana, 1994).

#### Labeling

Manufacturers recognize the potential for temperature abuse during distribution or storage of foods requiring refrigeration. Hence, they voluntarily use label statements, such as "keep refrigerated or "refrigerate after opening," to inform consumers of the need to maintain product at refrigeration temperatures (FDA, 1997).

The FDA determined in 1997 that the labeling of potentially hazardous foods that need refrigeration by consumers should be more specific about the types of hazards present and the necessary storage conditions after the food is opened and issued labeling guidance (FDA, 1997) to food manufacturers. The agency delineated foods that need refrigeration into three groups and developed model label statements and guidance on label placement and prominence. The model label statements refer to the importance of refrigeration for foods in two of the groups

to maintain safety and the use of refrigeration for foods in the third group to maintain quality.

#### Summary

A variety of high quality extended shelf life refrigerated foods is available. With attention to GMPs, sanitation, hygiene, product formulation, storage ternperature, length of refrigerated storage, and microbial control treatments, extended shelf

Table 4	Nonthermal	methods	to tr	eat foods.
Adapted	I from Youse	ef (1996).		•

Method	Mode of action on microbial cells
Pulsed electric fields	Rupture of cell membrane
Pulsed light	UV (or thermal) effect
ionizing radiation	DNA damage
High hydrostatic pressure	Denaturing of protein
Bacteriocins	Damage of cell membrane

life refrigerated foods will be of high quality and minimal risk for foodborne illness.

#### REFERENCES

Ahamad, N. and Marth, E.H. 1989. Behavior of Listeria monocytogenes at 7, 13, 21 and 35°C in tryptose broth acidified with acetic, citric or lactic acid. J. Food Protect. 52: 688-695

Bagi, L.K. and Buchanan, R.L. 1994. Purification and characterization of a bacteriocin produced by Camobacterium piscicola L.K. 5. Dairy Food Environ. Sanita. 14: 616 (Abstr.).

Brody, A.1996. Integrating aseptic and modified atmosphere packaging to fulfill a vision of tomorrow. Food Technol. 50(4): 56-66.

Buchanan, R.L. and Doyle, M.P. 1997. Foodborne disease significance of Escherichia coli 0157:H7 and other enterohemorrhagic E. coli. A Scientific Status Summary of the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition, Chicago, III., Food Technol. 51(10): 69-76.

Cliver, D.O. 1990. "Foodborne Diseases." Academic Press, Inc., San Diego, Calif.

Cliver, D.O. and Marth, E.H. 1990. Preservation, sanitation, and microbiological specifications for food. In "Foodborne Diseases," ed. D.O. Cliver, p. 45, Academic Press, Inc., San Diego, Calif.

Conner, D.E., Scott, V.N., and Bernard, D.T. 1989. Potential Clostridium botulinum hazards associated with extended shelf-life refrigerated foods: A review. J. Food Safety 10: 131-153.

Doyle, M.P. and Cliver, D.O. 1990. Yersinia enterocolitica. In "Foodborne Diseases," ed. D.O. Cliver, p. 223. Academic Press, Inc., San Diego, Calif.

Doyle, M.P., Beuchat, L.R., T.J. Montville. 1997. "Food Microbiology: Fundamentals and Frontiers." ASM Press, Herndon, Va.

Egan, A.F. and Grau, F.H. 1981. Environmental conditions and the role of Brochothrix thermosphacta in the spoilage of fresh and processed meat. In "Psychrotrophic Microorganisms in Spoilage and Pathogenicity," ed. T.A. Roberts, G. Hobbs, J.H.B. Christian and N. Skovgaard, p. 211, Academic Press, Inc., New York.

El-Shenawy, M.A. and Marth, E.H. 1988a. Sodium benzoate inhibits growth of or inactivates Listeria monocytogenes. J. Food Protect. 51: 525-530.

El-Shenawy, M.A. and Marth, E.H. 1988b. Inhibition and inactivation of Listeria monocytogenes by sorbic acid. J. Food Protect. 51: 842–847.

El-Shenawy, M.A. and Marth, E.H. 1989a. Inhibition and inactivation of Listeria monocytogenes by sodium benzoate together with some organic acids. J. cood Protect. 52: 771-776.

El-Shenawy, M.A. and Marth, E.H. 1989b. Behavior of Listeria monocytogenes in the presence of sodium propionate. Intern. J. Food Microbiol. 8: 85-94.

FDA. 1988. Nisin preparation: Affirmation of GRAS status as a direct human food ingredient. Food and Drug Admin., Fed. Reg. 53: 11247-11251.

FDA. 1994. M.G. Waldbaum Co.: Filing of petition for affirmation of GRAS status. Food and Drug Admin., Fed. Reg. 59: 12582-12583. Continued on next page

Table 3 Generation times or time until toxin formation by some psychrotrophic pathogens during growth in food. Adapted from Snyder (1996).

Temperature

Generation

Jana	°C'	°F	time (h)	
Listeria monocytogenes	0	32	110.0	Corned beef
	3	37	37.6	Roast beef
	4	39	36.0	Milk
4	5	41	43.0	Raw cabbage
	5	41	44.0	Cooked meat
	5	41	33.2	Ham
	10	50	21.7	Lettuce
	10	50	8.2	Corned beef
Yersinia enterocolitica	0	32	67.4	Imitation crab legs
	0	32	44.0	Oysters
	3	37	18.0	Boiled shrimp
• • •	7	45	10.3	Cooked beef
:	10	50	12.0	Imitation crab legs
Escherichia coli	10	50	5.2	Culture medium
Pathogen	Temper	ature	Time to toxin	Food
	°C'	° F	formation (h)	
Clostridium botulinum	3.3	38	744	Beef stew
type E	3.3	38	964	Fish
-yr	4.0	39	644	Fish
•	4.4	40	1320	Crabmeat
	5.0	41	426	Fish
	6.0	43	456	Beef stew
	7.0	45	243	Fish
	9.0	48	163	Fish
	10.0	50	138	Fish

# Extended Shelf Life

CONTINUED

FDA. 1995. Aplin & Barrett Ltd.: Filing of petition for affirmation of GRAS status. Food and Drug Admin., Fed. Reg. 60: 64167.

FDA. 1992. Foodborne Pathogenic Microorganisms and Natural Toxins Handbook, Center for Food Safety and Applied Nutrition, Food and Drug Administration, Wash-

FDA. 1996. Irradiation in the production, processing, and handling of food. Food and Drug Admin., Fed. Reg. 61: 42381-42383.

FDA. 1997. Guidance on labeling of foods that need refrigeration by consumers. Food and Drug Admin., Fed. Reg. 62: 8248-8252.

Frisvad, J.D. and Samson, R.A. 1991. Filamentous fungi in foods and feeds: Ecology, spoilage and mycotoxin production. In "Handbook of Applied Mycology," Vol. 3, "Foods and Feeds," ed. D.K. Arora, K.G. Mukerji and E.H. Marth, p. 31, Marcel Dekker, Inc., New York.

Garver, K.I. and Muriana, P.M. 1994. Purification and partial amino acid sequence of curvaticin FS47, a heatstable bacteriocin produced by Lactobacillus curvatus FS47. Appl. Environ. Microbiol. 60: 2191-2195.

Gill, C.O. 1986. The control of microbial spoilage in fresh meats. In "Advances in Meat Research," Vol. 2, "Meat and Poutry Microbiology," ed. A.M. Pearson and T.R. Dutson, p. 49, AVI Publishing Co., Westport, Conn.

Greer, G.G. 1989. Red meats, poutry and fish. In "Enzymes of Psychrotrophs in Raw Food," ed. R.C. McKellar, p. 267, CRC Press, Boca Raton, Fla.

Hatheway, C.L. 1992. Clostridium botulinum and other clostridia that produce botulinum neurotoxin. In "Clostridium botulinum: Ecology and Control in Foods," ed. A.H.W. Hauschild and K.L. Dodds, p. 3, Marcel Dekker, Inc.; New York.

Holck, A.L., Axelsson, L., Huhne, K. and Krockel, L. 1994. Purification and cloning of sakacin 674, a bacteriocin from Lactobacillus saki Lb 674. FEMS Microbiol. Lett.115: 143-149.

Huang, J., Lacroix, C., Daba, H. and Simard, R.E. 1993. Inhibition of growth of Listeria strains by mesenterocin 5 and organic acids. Lait 73: 357-370.

Huang, J., Lacroix, C., Daba, H. and Simard, R.E. 1994. Growth of Listeria monocytogenes in milk and its control by pediocin 5 produced by Pediococcus acidilactici UL5. Intern. Dairy J. 4: 429-443.

ICMSF, 1996. "Microorganisms in Foods 5: Microbiological Specifications of Pathogens." International Commission on Microbiological Specifications for Foods. Blackie Academic & Professional, an imprint of Chapman & Hall, New York.

Jay, J.M. 1987. Meats, poultry, and seafoods. In "Food and Beverage Mycology," 2nd Ed., ed. L.R. Beuchat, p. 155, Van Nostrand Reinhold, New York.

Jay, J.M. 1992. "Modern Food Microbiology." 4th Ed. Chapman & Hall, New York.

Jay. J.M. 1996. "Modern Food Microbiology." 5th Ed. Chapman & Hall, New York.

Kraft, A.A. 1986. Psychrotrophic organisms. In "Advances in Meat Research," Vol. 2, "Meat and Poultry Microbiology," ed. A.M. Pearson and T.R. Dutson, p. 191, AVI Publishing Co., Westport, Conn.

Kraft, A.A. 1992. Psychrotrophic Bacteria in Foods: Disease and Spoilage." CRC Press, Inc., Boca Raton, Fla. Labuza, T.P. 1996. An introduction to active packaging for foods. Food Technol. 50(4): 68-71.

Larsen, A.G. and Norrung, B. 1993. Inhibition of Listeria monocytogenes by bavaricin A, a bacteriocin produced by Lactobacillus bavaricus ML401. Lett. Appl. Microbiol. 17: 132-134.

Leistner, L. and Gorris, L.G.M. 1995. Food preservation by hurdle technology. Trends Food Sci. Technol. 6(2): 41-46. Maftah, A., Renault, D., Vignoles, C., Hechard, Y., Bressollier, P., Ratinand, M.H., Cenatiempo, Y. and Julien, R. 1993. Membrane permeabilization of Listena monocytogenes and mitochondria by the bacteriocin mesentericin Y105. J. Bacteriol. 175: 3232-3235

Martin, F., Friedrich, K., Beyer, F. and Terplan, G. 1994. influence of enterococci on the enrichment of Listeria manacytogenes. Arch. Lebensm. 45:75-79.

Mathieu, F., Michel, M., Lebrihi, A. and Lefebvre, G. 1994. Effect of the bacteriocin CP5 and of the producing strain Carnobacterium piscicola CP5 on the viability of Listeria monocytogenes ATCC15313 in salt solution, broth and skimmed milk at various incubation temperatures, Intern. J. Food Microbiol. 22: 155-172.

McLauchlin, J. 1996. The relationship between Listeria and listeriosis. Food Control 7(4/5): 187-193.

Moberg, L. 1989. Good manufacturing practices for refrigerated foods. J. Food Protect. 52: 363-367.

NACMCF, 1997. Hazard analysis and critical control point principles and application guidelines. National Advisory Committee on Microbiological Criteria for Foods. In press. NFPA. 1988. Safety considerations for new generation

refrigerated foods. Refrigerated Foods and Microbiological Criteria Committee of the National Food Processors Association. Dairy Food Sanita. 8(1): 5-7.

Olson, D.G. 1998. Irradiation of Food. A Scientific Status Summary of the Inst. Food Technologists' Expert Panel on Food Safety and Nutrition, Chicago, Ill., Food Technoi. 52(1): 56-62.

Olson, J.C., Jr. and Nottingham, P.M. 1980. Temperature. In "Microbial Ecology of Foods," Vol. 1, "Factors Affecting Life and Death of Microorganisms," ed. International Commission on Microbial Specifications for Foods, p. 1, Academic Press, Inc., New York.

Palumbo, S.A., Schuttz, J.J. and Williams, A.C. 1994. Influence of temperature on hemorrhagic Escherichia coli. Verotoxin production and minimum temperature of growth. Dairy Food Environ. Sanita. 14: 612 (Abstr.).

Park, H.S. and Marth, E.H. 1972. Inactivation of Salmonella typhimurium by sorbic acid. J. Milk Food Technol. 35: 532-539.

Park, H.S., Marth, E.H. and Olson, N.F. 1970. Survival of Salmonella typhimunium in cold-pack cheese food during refrigerated storage. J. Milk Food Technol. 33: 383-388.

Peck, M.W. 1997. Clostridium botulinum and the safety of refrigerated processed foods of extended durability. Trends Food Sci. Technol. 8: 186-192.

Pederson, C.S., Albury, M.N., Wilson, D.C. and Lawrence, N.L. 1959. The growth of yeasts in grape juice stored at low temperature. I. Control of yeast growth in commercial operation. Appl. Microbiol. 7: 1-6

Pin, C., Marin, M.L., Garcia, M.L., Tormo, J., Selgas, M.D.

and Casas, C. 1994. Incidence of motile Aeromonas spp. in foods. Microbiologia 10: 257–262.

Raffalli, J., Rosec, J.P., Carlez, A., Dumay, E., Richard, N. and Cheftel, J.C. 1994. High pressure stress and inactivation of Listeria innocua in inoculated dairy cream. Sci. Alim. 14: 349-358.

Rosenow, E.M. and Marth, E.H. 1987. Growth of Listeria monocytogenes in skim, whole and chocolate milk, and in whipping cream during incubation at 4, 8, 13, 21 and 35°C. J. Food Protect. 50: 452-459.

Ryser, E.T. and Marth, E.H. 1988. Survival of Listeria monocytogenes in cold-pack cheese food during refrigerated storage. J. Food Protect. 51: 615-621.

Ryser, E.T. and Marth, E.H. 1991. "Listeria, Listeriosis, and Food Safety," Marcel Dekker, Inc., New York.

Saad, S.M.I., Iaria, S.T. and Furlanetto, S.M.P. 1995. Motile Aeromonas spp. in retail vegetables from Sao Paulo, Brazil, Rev. Microbiol. 26: 22-27.

Schweizer, R., Kaderli, M. and Spahr, U. 1995. Aeromonas hydrophila in Swiss raw milk. Schweiz. Milchwirt. Forsch. 24: 9-11.

Scott, V.N. 1989. Interaction of factors to control microbial spoilage of refrigerated foods. J. Food Protect. 52: 431-435.

Sharpe, M.E. and Pettipher, G.L. 1983. Food spoilage by lactic acid bacteria. In "Food Microbiology," Vol. 8, ed. A.H. Rose, p. 200, Academic Press, Inc., New York.

Simpson, M.V., Smith, J.P., Dodds, K., Ramaswamy, H.S., Blanchfield, B., and Simpson, B.K. 1995. Challenge studies with Clostridium botulinum in a sous-vide spaghetti and meat-sauce product. J. Food Protect. 58: 229-234.

Snyder, O.P. 1996. Use of time and temperature specifications for holding and storing food in retail food operations. Dairy Food Environ. Sanita. 16: 374-388.

Splittstoesser, D.F. 1976. Gram-negative nonspore-forming rods. In "Food Microbiology: Public Health and Spoilage" Aspects," ed. M.P. Defigueiredo and D.F. Splittstoesser, p. 337, AVI Publishing Co., Westport, Conn.

Splittstoesser, D.F. 1987. Fruits and fruit products. In "Food and Beverage Mycology," 2nd ed., ed. L.R. Beuchat, p. 101, Van Nostrand Reinhold, New York.

Sugiyama, H. 1990. Botulism. In "Foodborne Diseases," ed. D.O. Cliver, p. 107, Academic Press, Inc., San Diego, Calif. Taoukis, P.S., Fu, B., and Labuza, T.P. 1991. Time-temperature indicators. Food Technol. 45(10): 70-82.

Tarelli, G.T., Carminati, D. and Giraffa, G. 1994. Production of bacteriocins active against Listeria monocytogenes and Listeria innocua from dairy enterococci. Food Microbiol. 11: 243-252.

Twedt, R.M. 1989. Vibrio parahaemolyticus. In "Foodborne Bacterial Pathogens," ed. M.P. Doyle, p. 543, Marcel Dekker, Inc., New York.

Yousef, A.E. 1996. Pulsed light and pulsed electric fields for cold-pasteurization of foods. Presented at the Annual Meeting of the Food Research Institute, University of Wisconsin, Madison, May 30.

# INSTITUTE OF FOOD TECHNOLOGISTS

The Society for Food Science and Technology

221 N. LaSalle St., Ste. 300, Chicago, IL 60601-1291 USA Tel. 312-782-8424 • Fax: 312-782-8348 E-mail: info@ift.org . URL: http://www.ift.org

This and other Scientific Status Summaries are published by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition in Food Technology. Scientific Status Summaries, which are not necessarily written by the Expert Panel, are rigorously peer-reviewed by the Expert Panel as well as by individuals outside the panel who have specific expertise in the subject. IFT's Expert Panel on Food Safety and Nutrition, which studies significant food-related issues and oversees timely production of Scientific Status Summaries, comprises academicians representing expertise in one or more areas of food science/technology and nutrition.

The Scientific Status Summaries may be reprinted or photocopied without permission, provided that suitable credit is given.

# Post Processing Pasteurization of Processed Meats

E. Jeffery Rhodehamel\* and Scott W. Beckwith

#### Introduction

Listeria monocytogenes became recognized as a foodborne pathogen in the early eighties. After several foodborne outbreaks the federal regulatory agencies established a "zero tolerance" for L. monocytogenes in ready-to-eat products. These events precipitated a new mindset by the meat industry that sanitation did not just involve food-contact surfaces, but rather the cleaning and sanitizing of the whole plant environment was necessary. Efforts to eradicate L. monocytogenes often involved clean room type sanitation standard operation procedures (SSOP's). These include rooms with positive air flow, sanitizing dips for hands and footwear, donning special clothing, and restricting access. Even with these, an occasional low level incidence of L. monocytogenes contamination can occur. Recent foodborne outbreaks and product recalls due **§1.** monocytogenes contamination have refocused the meat industry on potential post-processing intervention technolo-Post-processing intervention technologies would be used itan attempt to reduce or eliminate the hazard for those meat products that are unavoidably handled after the initial thernal processing. Potential technologies include: UV light; aninterobial films, irradiation, non-thermal processing methods uch as pulsed electric field (PEF), oscillating magnetic IPISSIOMF), and high pressure processing (HPP), and therin locessing methods using steam or hot water. The status, and potential of each of these technologies will be

# OSI-Processing Intervention Technologies UV Light

Plication. UV light has the potential for micro-Quction on foods, packaging materials, and food the lit is effective against a broad spectrum of Complex or irregular-shaped food surfaces

Sealed Air Corporation
Road, Bldg. A

aledair.com Officerence Proceedings, Volume 52, 1999. may possess light blocking folds or fissures that protect microorganisms from exposure.

### **Antimicrobial Packaging**

Several studies have reported the use of antimicrobial compounds either incorporated into or coated onto packaging films. Antimicrobial films are proposed as a means to provide an antimicrobial compound in direct food contact to extend shelf life through microbial spoilage and/or pathogen reduction. Another proposed use involves self sanitizing films that would reduce packaging as a source of microbial contamination. The ideal antimicrobial would be one that has broad spectrum antimicrobial activity, activity at low concentrations, thermostable for extrusion, controlled migration, no organoleptic effects, not inactivated by the food, and is inexpensive. Unfortunately, only a limited number of antimicrobial compounds have regulatory approval for use in foods, and these compounds are often more effective when added directly to the food product than through a film application.

#### Irradiation

Irradiation involves subjecting the food product to ionizing radiation either as gamma rays, E-beam, or X-rays. It can be effective against all microorganisms and could be used to post-pasteurize food products. There are considerable economic, logistic, sensory, packaging, and regulatory hurdles to overcome before irradiation will be widely used. Economic and logistic hurdles involve either the expense of building a radiation unit or transporting all food products to an existing unit. There are only a limited number of packaging materials that can be irradiated. Irradiation is currently only approved for use with raw meat and poultry. Use on processed meats is not approved and would require a food additive petition for approval.

# Non-Thermal Processing - Pulsed Electric Field

Pulsed electric field (PEF) involves subjecting the food product to a high electric field (35 to 75 kV/cm) pulse between two electrodes for a short period of time (pulse equals 1 to 4 microseconds). PEF can be performed in a continuous flow and is most suitable for low viscosity, homogeneous liquid products (i.e., juices). Generally intended as a pasteurization

effect at product temperatures < 50°C and with a total treatment time of 30 to 400 microseconds. PEF is most effective against vegetative cells and less effective against spores.

# Non-Thermal Processing - Oscillating Magnetic Fields

Oscillating Magnetic Fields (OMF) is an emerging technology that can inactivate microorganisms and denature some enzymes in either fresh or prepared foods. The technology involves subjecting the food to high energy OMF while generating minimal heat within the food. Potential applications involve solid and liquid foods in a flexible packaging. Currently, there are no commercial applications in use.

### **Non-Thermal Processing - High Pressure Processing**

High Pressure Processing (HPP) involves subjecting food products to a non-thermal extremely high hydrostatic pressure treatment (typically 70,000 to 130,000 psi or 500 to 900 Mpa). It is currently available as a batch or semi-continuous process. HPP is used to provide a pasteurization process because it is effective against vegetative microorganisms, but less effective against spores. Extreme pressures and slightly elevated temperatures have been shown to reduce Clostridium botulinum type E spores. HPP provides uniform pressure throughout the food product and retains food flavor/nutrients while providing a shelf life extension. Commercial applications involve jams, jellies, juices, guacamole, and sliced processed meats in Europe.

### Thermal Processing - Steam or Hot Water

Post-packaging heat treatments (typically referred to as post-pasteurization) have long been used for whole muscle products that are unavoidably handled after the initial thermal processing (Beckwith, 1995). Cryovac investigated the effectiveness of post-packaging heat treatments on shelf life extension and pathogen reduction in 1986, and was issued a post-pasteurization Statutory Invention Registration (DeMasi and Deily, 1990). Post-packaging heat treatments generally involve heat treatments of 160° to 205°F for time periods vary-

ing from 30 seconds to 10 minutes. Initial tests were performed to examine various time and temperature treatments efficacy on spoilage organisms that directly influence product shelf life. Use of CN530 and certain post-pasteurization treatments proved beneficial in controlling the microbial counts and extending the product shelf life by destroying surface organisms and/or extending the lag phase through microbial injury (Fig. ures 1 and 2). This generated interest in determining the effectiveness of these treatments on pathogen reduction and a second phase of testing was initiated. L. monocytogenes was surface inoculated on a cured ham product and subjected to various post-packaging heat treatments. Results showed that exposing the surface of a cured ham product to 205°F for either one or two minutes resulted in a 1 to 2 log reduction of L. monocytogenes (Figure 3). However, in no instance did the post-packaging heat treatments completely destroy all viable L. monocytogenes. Therefore we can not recommend that the treatments investigated in this study be used to ensure the safety of the food product, only as a means to extend shelf life. In addition, several other reports have shown the effectiveness of post-packaging heat treatments on reducing microbial populations (Cooksey, et al., 1993; Hardin, et al.,

Typical post-packaging heat treatments will not inactivate all organisms. Therefore, they should be used as a tool to increase the quality and shelf life of products that are unavoidably handled after the initial heat processing. Post-pasteurization heat treatments should not be viewed as a method to correct for unsanitary practices and good manufacturing practices must be maintained throughout processing.

#### References

 Beckwith, S. W. 1995. The effects of post-pasteurization on precooked meat and poultry. Cryovac Technical Report No. DPA-131. September, 1995.
 Cooksey, et al., 1993. Post-packaging pasteurization reduces Clostridium perfringens and other bacteria in precooked vacuum-packaged beef loin chunks. Journal of Food Science 56(2):239-241.

Demasi, T.W.; Deily, K.R. 1990. U.S. Statutory Invention Registration. Post-Pasteurization. Reg. Number: H762. Published: April 3, 1990.

Hardin, et al., 1993. Survival of *Listeria monocytogenes* in postpasteurized precooked beef roasts. Journal of Food Protection 56:655-660.



ELSEVIER

International Journal of Food Microbiology 55 (2000) 181-186

INTERNATIONAL JOURNAL OF Fo d Microbiol gy

www.elsevier.nl/locate/ijfoodmicro

#### Review

# Basic aspects of food preservation by hurdle technology

### Lothar Leistner\*

Former Director and Professor of the Federal Centre for Meat Research, An den Weinbergen 20, D-95326 Kulmbach, Germany

#### Abstract

Hurdle technology is used in industrialized as well as in developing countries for the gentle but effective preservation of foods. Previously hurdle technology, i.e., a combination of preservation methods, was used empirically without much knowledge of the governing principles. Since about 20 years the intelligent application of hurdle technology became more prevalent, because the principles of major preservative factors for foods (e.g., temperature, pH,  $a_w$ , Eh, competitive flora), and their interactions, became better known. Recently, the influence of food preservation methods on the physiology and behaviour of microorganisms in foods, i.e. their homeostasis, metabolic exhaustion, stress reactions, are taken into account, and the novel concept of multitarget food preservation emerged. In the present contribution a brief introduction is given on the potential hurdles for foods, the hurdle effect, and the hurdle technology. However, emphasis is placed on the homeostasis, metabolic exhaustion, and stress reactions of microorganisms related to hurdle technology, and the prospects of the future goal of a multitarget preservation of foods. © 2000 Elsevier Science BV. All rights reserved.

Keywords: Food preservation; Hurdle technology; Homeostasis; Metabolic exhaustion; Stress reactions; Multitarget preservation

#### 1. Introduction

The microbial safety and stability as well as the sensory and nutritional quality of most foods is based on an application of combined preservative factors (called hurdles). This is true for traditional foods with inherent empirical hurdles as well as for novel products for which the hurdles are intelligently selected and then intentionally applied (Leistner, 1995a).

# \*Tel: +49-9221-2446; fax: +49-9221-3779. E-mail address: L.Leistner@t-online.de (L. Leistner)

#### 1.1. Hurdles in foods

The most important hurdles used in food preservation are temperature (high or low), water activity  $(a_w)$ , acidity (pH), redox potential (Eh), preservatives (e.g., nitrite, sorbate, sulfite), and competitive microorganisms (e.g., lactic acid bacteria). However, more than 60 potential hurdles for foods, which improve the stability and/or quality of the products, have been already described, and the list of possible hurdles for food preservation is by no means complete (Leistner, 1999a). Some hurdles (e.g., Maillard reaction products) will influence the safety and the quality of foods, because they have antimicrobial properties and at the same time improve the flavour of the products. The same hurdle could have a

positive or a negative effect on foods, depending on its intensity. For instance, chilling to an unsuitable low temperature is detrimental to some foods of plant origin ('chilling injury'), whereas moderate chilling will be beneficial for their shelf life. Another example is the pH of fermented sausage which should be low enough to inhibit pathogenic bacteria, but not so low as to impair taste. If the intensity of a particular hurdle in a food is too small it should be strengthened, if it is detrimental to the food quality it should be lowered. By this adjustment, hurdles in foods can be kept in the optimal range, considering safety as well as quality, and thus the total quality of a food (Leistner, 1994a).

For each stable and safe food a certain set of hurdles is inherent, which differs in quality and intensity depending on the particular product, but in any case the hurdles must keep the 'normal' population of microorganisms in this food under control. The microorganisms present ('at the start') in a food should not be able to overcome ('leap over') the hurdles present during the storage of a product, otherwise the food will spoil or even cause food poisoning. This situation is illustrated by the hurdle effect, first introduced by Leistner (1978), which is of fundamental importance for the preservation of intermediate-moisture foods (Leistner and Rödel, 1976) as well as high-moisture foods (Leistner et al., 1981).

#### 2. Hurdle technology

From an understanding of the hurdle effect, the hurdle technology has been derived (Leistner, 1985), which means that hurdles are deliberately combined to improve the microbial stability and the sensory quality of foods as well as their nutritional and economic properties. Thus, hurdle technology aims to improve the total quality of foods by application of an intelligent mix of hurdles. Over the years the insight into the hurdle effect has been broadened and the application of hurdle technology was extended (Leistner and Gorris, 1994).

In industrialized countries the hurdle technology approach is currently of most interest for minimally processed foods which are mildly heated or fermented (Leistner, 2000), and for underpinning the

microbial stability and safety of foods coming from future lines, e.g., healthful foods with less fat and/or salt (Leistner, 1997) or advanced hurdle-technology foods requiring only minimal packaging (Kentaro Ono, Snow Brand Tokyo, Japan, personal communication, 1996; Leistner, 1996). For refrigerated foods chill temperatures are the major and sometimes the only hurdle. However, if exposed to temperature abuse during distribution of the foods, this hurdle breaks down, and spoilage or food poisoning could happen. Therefore, additional hurdles should be incorporated as safeguards into chilled foods, using an approach called 'invisible technology' (Leistner, 1999a).

In developing countries the application of hurdle technology for foods that remain stable, safe, and tasty if stored without refrigeration is of paramount importance, and has made impressive strides, especially in Latin America with the development of novel minimally processed, high-moisture fruit products. However, much interest in intentional hurdle technology is also emerging for meat products in China as well as for dairy products in India. There is a general trend in developing countries to move gradually away from intermediate-moisture foods, because they are often too salty or too sweet and have a less appealing texture and appearance than high-moisture foods, and this goal could be achieved by the application of intelligent hurdle technology. The progress made in the use of advanced hurdle technology in Latin America, China, India, and Africa has recently been reviewed by Leistner (1999b).

#### 3. Basic aspects

Food preservation implies putting microorganisms in a hostile environment, in order to inhibit their growth or shorten their survival or cause their death. The feasible responses of microorganisms to this hostile environment determine whether they may grow or die. More research is needed in view of these responses; however, recent advances have been made by considering the homeostasis, metabolic exhaustion, and stress reactions of microorganisms in relation to hurdle technology, as well as by introducing the novel concept of multitarget preservation

for a gentle but most effective preservation of hurdle-technology foods (Leistner, 1995a,b).

#### 3.1. Homeostasis

Homeostasis is the tendency to uniformity and stability in the internal status of organisms. For instance, the maintenance of a defined pH is a prerequisite and feature of living cells, and this applies to higher organisms as well as to microorganisms (Häussinger, 1988). Much is already known about homeostasis in higher organisms at the molecular, subcellular, cellular, and systemic levels in the fields of pharmacology and medicine (Häussinger, 1988). This knowledge should be transfered to microorganisms important for the poisoning and spoilage of foods. In food preservation the homeostasis of microorganisms is a key phenomenon which deserves much attention, because if the homeostasis of these microorganisms is disturbed by preservative factors (hurdles) in foods, they will not multiply, i.e. they remain in the lag-phase or even die, before homeostasis is repaired (re-established). Therefore, food preservation is achieved by disturbing the homeostasis of microorganisms in a food temporarily or permanently. Gould (1988, 1995) was the first to draw attention to the interference by the food with the homeostasis of the microorganisms present in this food, and more work in this direction is certainly warranted.

#### 3.2. Metabolic exhaustion

Another phenomenon of practical importance is metabolic exhaustion of microorganisms, which could cause 'autosterilization' of a food. This was first observed in experiments with mildly heated (95°C core temperature) liver sausage adjusted to different water activities by the addition of salt and fat, and the product was inoculated with Clostridium sporogenes and stored at 37°C. Clostridial spores surviving the heat treatment vanished in the product during storage, if the products were stable (Leistner and Karan-Djurdjić, 1970). Later this behaviour of Clostridium and Bacillus spores was regularly observed during storage of shelf stable meat products (SSP), if these products were stored at ambient temperature (Leistner, 1994b). The most likely explanation is that bacterial spores which survive the

heat treatment are able to germinate in these foods under less favourable conditions than those under which vegetative bacteria are able to multiply (Leistner, 1992). Thus, the spore counts in stable hurdletechnology foods actually decrease during storage of the products, especially in unrefrigerated foods. Also during studies in our laboratory with Chinese dried meat products the same behaviour of microorganisms was observed. If these meats were contaminated after processing with staphylococci, salmonellae or yeasts, the counts of these microorganisms on stable products decreased quite fast during unrefrigerated storage, especially on meats with a water activity close to the threshold for microbial growth. Latin American researchers (Alzamora et al., 1995; Tapia de Daza et al., 1996) observed the same phenomenon in studies with high-moisture fruit products, because the counts of a variety of bacteria, yeasts, and moulds which survived the mild heat treatment, decreased fast in the products during unrefrigerated storage, since the hurdles applied (pH, a, sorbate, sulfite) did not allow growth.

A general explanation for this surprising behaviour might be that vegetative microorganisms which cannot grow will die, and they die more quickly if the stability is close to the threshold for growth, storage temperature is elevated, antimicrobials are present, and the microorganisms are sublethally injured (Leistner, 1995a). Apparently, microorganisms in stable hurdle-technology foods strain every possible repair mechanisms for their homeostasis to overcome the hostile environment, by doing this they completely use up their energy and die, if they become metabolically exhausted. This leads to an autosterilization of such foods (Leistner, 1995b). Due to autosterilization hurdle-technology foods, which are microbiologically stable, become more safe during storage, especially at ambient temperatures. For example, salmonellae that survive the ripening process in fermented sausages will vanish more quickly if the products are stored at ambient temperature, and they will survive longer and possibly cause foodborne illness if the products are stored under refrigeration (Leistner, 1995a). It is also well known that salmonellae survive in mayonnaise at chill temperatures much better than at ambient temperatures. Unilever laboratories at Vlaardingen have confirmed metabolic exhaustion in water-in-oil emulsions (resembling margarine) inoculated with

Listeria innocua. In these products listeria vanished faster at ambient temperature (25°C) than under refrigeration (7°C), at pH 4.25 > pH 4.3 > pH 6.0, in fine emulsions more quickly than in coarse emulsions, under anaerobic conditions more quickly than under aerobic conditions. From these experiments it has been concluded that metabolic exhaustion is accelerated if more hurdles are present, and this might be caused by increasing energy demands to maintain internal homeostasis under stress conditions (P.F. ter Steeg, personal communication, 1995). Thus, it could be concluded that refrigeration is not always beneficial for the microbial safety and stability of foods. However, this is only true if the hurdles present in a food inhibit the growth of microorganisms also without refrigeration, if this is not the case then refrigeration is beneficial. Certainly, the survival of microorganisms in stable hurdle-technology foods is much shorter without refrigeration.

#### 3.3. Stress reactions

Some bacteria become more resistant or even more virulent under stress, since they generate stress shock proteins. The synthesis of protective stress shock proteins is induced by heat, pH, a, ethanol, oxidative compounds, etc. as well as by starvation. Stress reactions might have a non-specific effect, since due to a particular stress microorganisms become also more tolerant to other stresses, i.e. they acquire a 'cross-tolerance'. The various responses of microorganisms under stress might hamper food preservation and could turn out to be problematic for the application of hurdle technology. On the other hand, the activation of genes for the synthesis of stress shock proteins, which help organisms to cope with stress situations, should be more difficult if different stresses are received at the same time. Simultaneous exposure to different stresses will require energy-consuming synthesis of several or at least much more protective stress shock proteins, which in turn may cause the microorganisms to become metabolically exhausted. Therefore, multitarget preservation of foods could be the key to avoiding synthesis of stress shock proteins, which otherwise could jeopardize the microbial stability and safety of hurdle-technology foods (Leistner, 1995b).

#### 3.4. Multitarget preservation

The concept of multitarget preservation of foods has been introduced recently by Leistner (1995a,b). Multitarget preservation of foods should be the ambitious goal for a gentle but most effective preservation of foods (Leistner, 1995b). It has been suspected for some time that different hurdles in a food might not have just an additive effect on microbial stability, but they could act synergistically (Leistner, 1978). A synergistic effect could be achieved if the hurdles in a food hit, at the same time, different targets (e.g., cell membrane, DNA, enzyme systems, pH,  $a_w$ , Eh) within the microbial cells and thus disturb the homeostasis of the microorganisms present in several respects. If so, the repair of homeostasis as well as the activation of stress shock proteins become more difficult (Leistner, 1995a). Therefore, employing simultaneously different hurdles in the preservation of a particular food should lead to optimal microbial stability. In practical terms, this could mean that it is more effective to employ different preservative factors (hurdles) of small intensity than one preservative factor of larger intensity, because different preservative factors might have a synergistic effect (Leistner, 1994a).

It is anticipated that the targets in microorganisms of different preservative factors for foods will be elucidated, and that hurdles could then be grouped in classes according to their targets. A mild and effective preservation of foods, i.e. a synergistic effect of hurdles, is likely if the preservation measures are based on intelligent selection and combination of hurdles taken from different target classes (Leistner, 1995a). This approach is probably not only valid for traditional food-preservation procedures, but as well for modern processes such as food irradiation, ultrahigh pressure, pulsed technologies (Barbosa-Cánovas et al., 1998). Food microbiologists could learn from pharmacologists, because the mechanisms of action of biocides have been studied extensively in the medical field. At least 12 classes of biocides are already known which have different targets, and sometimes more than one, within the microbial cell. Often the cell membrane is the primary target, becoming leaky and disrupting the organism, but biocides also impair the synthesis of enzymes,

proteins, and DNA (Denyer and Hugo, 1991). Multidrug attack has proven successful in the medical field to fight bacterial infections (e.g., tuberculosis) as well as viral infections (e.g., AIDS), and thus a multitarget attack on microorganisms should also be a promising approach in food microbiology (Leistner, 1995b).

#### 4. Conclusions

The physiological responses of microorganisms during food preservation (i.e., their homeostasis, metabolic exhaustion, and stress reactions) are the basis for the application of advanced hurdle technology. The disturbance of the homeostasis of microorganisms is the key phenomenon of food preservation. Microbial stress reactions may complicate food preservation, whereas the metabolic exhaustion of microorganisms present in stable hurdle-technology foods could foster food preservation. The novel and ambitious goal for an optimal food preservation is the multitarget preservation of foods, in which intelligently applied gentle hurdles will have a synergistic effect. After the targets of different preservative factors within the microbial cells have been elucidated, and this should become definitely a major research topic in the future, preservation of foods could progress far beyond the state-of-the-art of the hurdle technology approach as we know it today.

#### References

- Alzamora, S.M., Cerrutti, P., Guerrero, S., López-Malo, A., 1995. Minimally processed fruits by combined methods. In: Barbosa-Cánovas, G.V., Welt-Chanes, J. (Eds.), Food Preservation by Moisture Control: Fundamentals and Applications, Technomics Publishing, Lancaster, Pennsylvania, pp. 463-492.
- Barbosa-Cánovas, G.V., Pothakamury, U.R., Palou, E., Swanson, B.G., 1998. Nonthermal Preservation of Foods, Marcel Dekker, New York, p. 276.
- Denyer, S.P., Hugo, W.B. (Eds.), 1991. Mechanisms of Action of Chemical Biocides: Their Study and Exploitation, Blackwell Scientific Publications, London, UK, p. 343.
- Gould, G.W., 1988. Interference with homeostasis-food. In: Whittenbury, R., Gould, G.W., Banks, J.G., Board, R.G. (Eds.), Homeostatic Mechanisms in Micro-organisms, Bath University Press, Bath, pp. 220-228.

- Gould, G.W., 1995. Homeostatic mechanisms during food preservation by combined methods. In: Barbosa-Cánovas, G.V., Welti-Chanes, J. (Eds.), Food Preservation by Moisture Control: Fundamentals and Applications, Technomics Publishing, Lancaster, Pennsylvania, pp. 397-410.
- Häussinger, D. (Ed.), 1988. pH Homeostasis: Mechanisms and Control, Academic Press, London, p. 479.
- Leistner, L., 1978. Hurdle effect and energy saving. In: Downey, W.K. (Ed.), Food Quality and Nutrition, Applied Science Publishers, London, UK, pp. 553-557.
- Leistner, L., 1985. Hurdle technology applied to meat products of the shelf stable product and intermediate moisture food types.
   In: Simatos, D., Multon, J.L. (Eds.), Properties of Water in Foods in Relation to Quality and Stability, Martinus Nijhoff Publishers, Dordrecht, Netherlands, pp. 309-329.
- Leistner, L., 1992. Food preservation by combined methods. Food Res. Internat. 25, 151-158.
- Leistner, L., 1994a. Further developments in the utilization of hurdle technology for food preservation. J. Food Engineering 22, 421-432.
- Leistner, L., 1994b. Food Design by Hurdle Technology and HACCP, Printed and distributed by the Adalbert-Raps-Foundation, Kulmbach, Germany, p. 62.
- Leistner, L., 1995a. Principles and applications of hurdle technology. In: Gould, G.W. (Ed.), New Methods for Food Preservation, Blackie Academic and Professional, London, pp. 1-21.
- Leistner, L., 1995b. Emerging concepts for food safety. In: 41st International Congress of Meat Science and Technology, 20— 25 August 1995, San Antonio, Texas, pp. 321-322.
- Leistner, L., 1996. Food protection by hurdle technology. Bull. Jpn. Soc. Res. Food Prot. 2, 2-26.
- Leistner, L., 1997. Microbial stability and safety of healthy meat, poultry and fish products. In: Pearson, A.M., Dutson, T.R. (Eds.), Production and Processing of Healthy Meat, Poultry and Fish Products, Blackie Academic and Professional, London, pp. 347-360.
- Leistner, L., 1999a. Combined methods for food preservation. In: Shafiur Rahman, M. (Ed.), Handbook of Food Preservation, Marcel Dekker, New York, pp. 457-485.
- Leistner, L., 1999b. Use of combined preservative factors in foods of developing countries. In: Lund, B.M., Baird-Parker, A.C., Gould, G.W. (Eds.), The Microbiological Safety of Foods, Aspen Publishers, Gaithersburg, Maryland, in press.
- Leistner, L., 2000. Hurdle technology in the design of minimally processed foods. In: Alzamora, S.M., Tapia,M.S., López-Malo, A. (Eds.), Design of Minimal Processing Technologies for Fruits and Vegetables, Aspen Publishers, Gaithersburg, Maryland, in press.
- Leistner, L., Karan-Djurdjić, S., 1970. Beeinflussung der Stabilität von Fleischkonserven durch Steuerung der Wasseraktivität. Fleischwirtschaft 50, 1547-1549.
- Leistner, L., Rödel, W., 1976. The stability of intermediate moisture foods with respect to micro-organisms. In: Davies, R., Birch, G.G., Parker, K.J. (Eds.), Intermediate Moisture Foods, Applied Science Publishers, London, pp. 120-137.
- Leistner, L., Gorris, L.G.M. (Eds.), 1994. Food Preservation by Combined Processes. Final Report of FLAIR Concerted Action

No. 7, Subgroup B, EUR 1577 EN, European Commission, Directorate-General XII, Brussels, Belgium, p. 100.

Leistner, L., Rödel, W., Krispien, K., 1981. Microbiology of meat and meat products in high- and intermediate-moisture ranges.

In: Rockland, L.B., Stewart, G.F. (Eds.), Water Activity:

Influences on Food Quality, Academic Press, New York, pp. 855-916.

Tapia de Daza, M.S., Alzamora, S.M., Welti Chanes, J., 1996.
Combination of preservation factors applied to minimal processing of foods. Crit. Rev. Food Sci. and Nutr. 36, 629-659.